REPORT #
RRTAC 88-2

Plains Hydrology And Reclamation Project: Spoil Groundwater Chemistry And Its Impacts On Surface Water

Heritage Fund

Alberta
LAND CONSERVATION AND
RECLAMATION COUNCIL
Reclamation Research
Technical Advisory Committee

REPORT NO. RRTAC 88-2

PLAINS HYDROLOGY AND RECLAMATION PROJECT:
SPOIL GROUNDWATER CHEMISTRY
AND ITS IMPACTS ON SURFACE WATER

Compiled by
MARK R. TRUDELL
Alberta Research Council

Prepared for
The Plains Coal Reclamation Research Program
of
THE LAND CONSERVATION AND RECLAMATION COUNCIL
(Reclamation Research Technical Advisory Committee)

1988

STATEMENT OF OBJECTIVE

The recommendations and conclusions in this report are those of the authors and not those of the Alberta Government or its representatives.

This report is intended to provide government and industry staff with up-to-date technical information to assist in the development of guidelines and operating procedures. The report is also available to the public so that interested individuals similarly have access to the best available information on land reclamation topics.

ALBERTA'S RECLAMATION RESEARCH PROGRAM

The regulation of surface disturbances in Alberta is the responsibility of the Land Conservation and Reclamation Council. The Council executive consists of a Chairman from the Department of Forestry, Lands and Wildlife. Among other functions, the Council oversees programs for reclamation of abandoned disturbances and reclamation research. The Reclamation Research Program was established to provide answers to the many practical questions which arise in reclamation. Funds for implementing both the operational and research programs are drawn from Alberta's Heritage Savings Trust Fund.

To assist in technical matters related to the development and administration of the Research Program, the Council appointed the Reclamation Research Advisory Committee (RRTAC). The Committee first met in March 1978 and consists of eight members representing the Alberta Departments of Agriculture, Energy, Forestry, Lands and Wildlife, Environment and the Alberta Research Council. The Committee meets regularly to update research priorities, review solicited and unsolicited research proposals, arrange workshops and otherwise act as a referral and coordinating body for Reclamation Research.

Additional information on the Reclamation Research Program may be obtained by contacting:

Dr. G.A. Singleton, Chairman
Reclamation Research Technical Advisory Committee
Alberta Environment
4th Floor, Oxbridge Place
9820 - 106 Street
Edmonton, Alberta T5K 2J6

(403) 427-5868

This report may be cited as: Trudell, M.R. (compiler) 1988. Plains Hydrology and Reclamation Project: Spoil Groundwater Chemistry and its Impacts on Surface Water. Alberta Land Conservation and Reclamation Council Report #RRTAC 88-2. 135 pages.

Additional copies may be obtained from:

Publication Services
Queen's Printer
11510 Kingsway Avenue
Edmonton, Alberta T5G 2Y5

RECLAMATION RESEARCH REPORTS

** 1. RRTAC 80-3: The Role of Organic Compounds in Salinization of Plains Coal Mining Sites. N.S.C. Cameron et al. 46 pp.

DESCRIPTION: This is a literature review of the chemistry of sodic mine spoil and the changes expected to occur in groundwater.

** 2. RRTAC 80-4: Proceedings: Workshop on Reconstruction of Forest Soils in Reclamation. P.F. Ziemkiewicz, S.K. Takyi, and H.F. Regier. 160 pp.

DESCRIPTION: Experts in the field of forestry and forest soils report on research relevant to forest soil reconstruction and discuss the most effective means of restoring forestry capability of mined lands.

N/A 3. RRTAC 80-5: Manual of Plant Species Suitability for Reclamation in Alberta. L.E. Watson, R.W. Parker, and P.F. Polster. 2 vols, 541 pp.

DESCRIPTION: Forty-three grass, fourteen forb, and thirty-four shrub and tree species are assessed in terms of their fitness for use in Reclamation. Range maps, growth habit, propagation, tolerance, and availability information are provided.

N/A 4. RRTAC 81-2: 1980 Survey of Reclamation Activities in Alberta. D.G. Walker and R.L. Rothwell. 76 pp.

DESCRIPTION: This survey is an update of a report prepared in 1976 on reclamation activities in Alberta, and includes research and operational reclamation, locations, personnel, etc.

N/A 5. RRTAC 81-3: Proceedings: Workshop on Coal Ash and Reclamation. P.F. Ziemkiewicz, R. Stien, R. Leitch, and G. Lutwick. 253 pp.

DESCRIPTION: Presents nine technical papers on the chemical, physical and engineering properties of Alberta fly and bottom ashes, revegetation of ash disposal sites and use of ash as a soil amendment. Workshop discussions and summaries are also included.

N/A 6. RRTAC 82-1: Land Surface Reclamation: An International Bibliography. H.P. Sims and C.B. Powter. 2 vols, 292 pp.

DESCRIPTION: Literature to 1980 pertinent to reclamation in Alberta is listed in Vol. 1 and is also on the University of Alberta computing system. Vol. 2 comprises the keyword index and computer access manual.

N/A 7. RRTAC 82-2: A Bibliography of Baseline Studies in Alberta: Soils, Geology, Hydrology and Groundwater. C.B. Powter and H.P. Sims. 97 pp.

DESCRIPTION: This bibliography provides baseline information for persons involved in reclamation research or in the preparation of environmental impact assessments. Materials, up to date as of December 1981, are available from the Alberta Environment Library.

N/A 8. RRTAC 83-1: Soil Reconstruction Design for Reclamation of Oil Sand Tailings. Monenco Consultants Ltd. 185 pp.

DESCRIPTION: Volumes of peat and clay required to amend oil sand tailings were estimated based on existing literature. Separate soil prescriptions were made for spruce, jack pine, and herbaceous cover types. The estimates form the basis of field trials.

N/A 9. RRTAC 83-3: Evaluation of Pipeline Reclamation Practices on Agricultural Lands in Alberta. Hardy Associates (1978) Ltd. 205 pp.

DESCRIPTION: Available information on pipeline reclamation practices was reviewed. A field survey was then conducted to determine the effects of pipe size, age, soil type, construction method, etc. on resulting crop production.

N/A 10. RRTAC 83-4: Proceedings: Effects of Coal Mining on Eastern Slopes Hydrology. P.F. Ziemkiewicz. 123 pp.

DESCRIPTION: Technical papers are presented dealing with the impacts of mining on mountain watersheds, their flow characteristics and resulting water quality. Mitigative measures and priorities were also discussed.

N/A 11. RRTAC 83-5: Woody Plant Establishment and Management for Oil Sands Mine Reclamation. Techman Engineering Ltd. 124 pp.

DESCRIPTION: This is a review and analysis of information on planting stock quality, rearing site preparation, planting and procedures necessary to ensure survival of trees and shrubs in oil sand reclamation.

*** 12. RRTAC 84-1: Land Surface Reclamation: A Review of International Literature. H.P. Sims, C.B. Powter, and J.A. Campbell. 2 vols, 1549 pp.

DESCRIPTION: Nearly all topics of interest to reclamation including mining methods, soil amendments, revegetation, propagation and toxic materials are reviewed in light of the international literature.

** 13. RRTAC 84-2: Propagation Study: Use of Trees and Shrubs for Oil Sand Reclamation. Techman Engineering Ltd. 58 pp.

DESCRIPTION: This report evaluates and summarizes all available published and unpublished information on large-scale propagation methods for shrubs and trees to be used in oil sand reclamation.

* 14. RRTAC 84-3: Reclamation Research Annual Report - 1983. P.F. Ziemkiewicz. 42 pp.

DESCRIPTION: This report details the Reclamation Research Program indicating priorities, descriptions of each research project, researchers, results and expenditures.

** 15. RRTAC 84-4: Soil Microbiology in Land Reclamation. D. Parkinson, R.M. Danielson, C. Griffiths, S. Visser, and J.C. Zak. 2 vols, 676 pp.

DESCRIPTION: This is a collection of five reports dealing with re-establishment of fungal decomposers and mycorrhizal symboints in various amended spoil types.

** 16. RRTAC 85-1: Proceedings: Revegetation Methods for Alberta's Mountains and Foothills. P.F. Ziemkiewicz. 416 pp.

DESCRIPTION: Results of long-term experiments and field experience on species selection, fertilization, reforestation, topsoiling, shrub propagation and establishment are presented.

* 17. RRTAC 85-2: Reclamation Research Annual Report - 1984. P.F. Ziemkiewicz. 29 pp.

DESCRIPTION: This report details the Reclamation Research Program indicating priorities, descriptions of each research project, researchers, results and expenditures.

** 18. RRTAC 86-1: A Critical Analysis of Settling Pond Design and Alternative Technologies. A. Somani. 372 pp.

DESCRIPTION: The report examines the critical issue of settling pond design and sizing and alternative technologies.

** 19. RRTAC 86-2: Characterization and Variability of Soil Reconstructed after Surface Mining in Central Alberta. T.M. Macyk. 146 pp.

DESCRIPTION: Reconstructed soils representing different materials handling and replacement techniques were characterized and variability in chemical and physical properties was assessed. The data obtained indicate that reconstructed soil properties are determined largely by parent material characteristics and further tempered by materials handling procedures. Mining tends to create a relatively homogeneous soil landscape in contrast to the mixture of diverse soils found before mining.

* 20. RRTAC 86-3: Generalized Procedures for Assessing Post-Mining Groundwater Supply Potential in the Plains of Alberta - Plains Hydrology and Reclamation Project. M.R. Trudell and S.R. Moran. 30 pp.

DESCRIPTION: In the Plains region of Alberta, the surface mining of coal generally occurs in rural, agricultural areas in which domestic water supply requirements are met almost entirely by groundwater. Consequently, an important aspect of the capability of reclaimed lands to satisfy the needs of a residential component is the post-mining availability of groundwater. This report proposes a sequence of steps or procedures to identify and characterize potential post-mining aquifers.

** 21. RRTAC 86-4: Geology of the Battle River Site: Plains Hydrology and Reclamation Project. A Maslowski-Schutze, R. Li, M. Fenton and S.R. Moran. 86 pp.

DESCRIPTION: This report summarzies the geological setting of the Battle River study site. It is designed to provide a general understanding of geological conditions adequate to establish a framework for hydrogeological and general reclamation studies. The report is not intended to be a detailed synthesis such as would be required for mine planning purposes.

** 22. RRTAC 86-5: Chemical and Mineralogical Properties of Overburden: Plains Hydrology and Reclamation Program. A. Maslowski-Schutze. 71 pp.

DESCRIPTION: This report describes the physical and mineralogical properties of overburden materials in an effort to identify individual beds within the bedrock overburden that might be significantly different in terms of reclamation potential.

* 23. RRTAC 86-6: Post-Mining Groundwater Supply at the Battle River Site: Plains Hydrology and Reclamation Project. M.R. Trudell, G.J. Sterenberg and S.R. Moran. 49 pp.

DESCRIPTION: The report deals with the availability of water supply in or beneath cast overburden at the Battle River Mining area in east-central Alberta to support post-mining land use. Both groundwater quantity and quality are evaluated.

* 24. RRTAC 86-7: Post-Mining Groundwater Supply at the Highvale Site: Plains Hydrology and Reclamation Project. M.R. Trudell. 25 pp.

DESCRIPTION: This report evaluates the availability of water supply in or beneath cast overburden to support post-mining land use, including both quantity and quality considerations. The study area is the Highvale mining area in west-central Alberta.

* 25. RRTAC 86-8: Reclamation Research Annual Report - 1985. P.F. Ziemkiewicz. 54 pp.

DESCRIPTION: This report details the Reclamation Research Program indicating priorities, descriptions of each research project, researchers, results and expenditures.

** 26. RRTAC 86-9: Wildlife Habitat Requirements and Reclamation Techniques for the Mountains and Foothills of Alberta. J.E. Green, R.E. Salter and D.G. Walker. 285 pp.

DESCRIPTION: This report presents a review of relevant North American literature on wildlife habitats in mountain and foothills biomes, reclamation techniques, potential problems in wildlife habitat reclamation, and potential habitat assessment methodologies. Four biomes (Alpine, Subalpine, Montane, and Boreal Uplands) and 10 key wildlife species (snowshoe hare, beaver, muskrat, elk, moose, caribou, mountain goat, bighorn sheep, spruce grouse, and white-tailed ptarmigan) are discussed.

** 27. RRTAC 87-1: Disposal of Drilling Wastes. L.A. Leskiw, E. Reinl-Dwyer, T.L. Dabrowski, B.J. Rutherford and H. Hamilton. 210 pp.

DESCRIPTION: Current drilling waste disposal practices are reviewed and criteria in Alberta guidelines are assessed. The report also identifies research needs and indicates mitigation measures. A manual included provides a decision-making flowchart to assist in selecting methods of environmentally safe waste disposal.

** 28. RRTAC 87-2: Minesoil and Landscape Reclamation of the Coal Mines in Alberta's Mountains and Foothills. A.W. Fedkenheuer, L.J. Knapik, and D.G. Walker. 174 pp.

DESCRIPTION: This report reviews current reclamation practices with regard to site and soil reconstruction and re-establishment of biological productivity. It also identifies research needs in the Mountain-Foothills area.

** 29. RRTAC 87-3: Gel and Saline Drilling Wastes in Alberta: Workshop Proceedings. D.A. Lloyd (compiler). 218 pp.

DESCRIPTION: Technical papers were presented which describe: the mud systems used and their purpose; industrial constraints; government regulations, procedures and concerns; environmental considerations in waste disposal; and toxic constituents of drilling wastes. Answers to a questionnaire distributed to participants are included in an appendix.

* 30. RRTAC 87-4: Reclamation Research Annual Report - 1986. 50 pp.

DESCRIPTION: This report details the Reclamation Research Program indicating priorities, descriptions of each research project, researchers, results and expenditures.

* 31. RRTAC 87-5: Review of the Scientific Basis of Water Quality Criteria for the East Slope Foothills of Alberta. Beak Associates Consulting Ltd. 46 pp.

DESCRIPTION: The report reviews existing Alberta guidelines to assess the quality of water drained from coal mine sites in the East Slope Foothills of Alberta. World literature was reviewed within the context of the east slopes environment and current mining operations. The ability of coal mine operators to meet the various guidelines is discussed.

** 32. RRTAC 87-6: Assessing Design Flows and Sediment Discharge on the Eastern Slopes. Hydrocon Engineering (Continental) Ltd. and Monenco Consultants Ltd. 97 pp.

DESCRIPTION: The report provides an evaluation of current methodologies used to determine sediment yields due to rainfall events in well-defined areas. Models are available in Alberta to evaluate water and sediment discharge in a post-mining situation. SEDIMOT II (Sedimentology Disturbed Modelling Techniques) is a single storm model that was developed specifically for the design of sediment control structures in watersheds disturbed by surface mining and is well suited to Alberta conditions.

* 33. RRTAC 87-7: The Use of Bottom Ash as an Amendment to Sodic Spoil. S. Fullerton. 83 pp.

DESCRIPTION: The report details the use of bottom ash as an amendment to sodic coal mine spoil. Several rates and methods of application of bottom ash to sodic spoil were tested to determine which was the best at reducing the effects of excess sodium and promoting crop growth. Field trials were set up near the Vesta mine in East Central Alberta using ash readily available from nearby coal-fired thermal generating station. The research indicated that bottom ash incorporated to a depth of 30 cm using a subsoiler provided the best results.

* 34. RRTAC 87-8: Waste Dump Design for Erosion Control. R.G. Chopiuk and S.E. Thornton. 45 pp.

DESCRIPTION: This report describes a study to evaluate the influence of erosion from reclaimed waste dumps on downslope environments such as streams and rivers. Sites were selected from coal mines in Alberta's mountains and foothills, and included resloped dumps of different configurations and ages, and having different vegetation covers. The study concluded that the average annual amount of surface erosion is minimal. As expected, erosion was greatest on slopes which were newly regraded. Slopes with dense grass cover showed no signs of erosion. Generally, the amount of erosion decreased with time, as a result of initial loss of fine particles, the formation of a weathered surface, and increased vegetative cover.

** 35. RRTAC 87-9: Hydrogeology and Groundwater Chemistry of the Battle River Mining Area. M.R. Trudell, R.L. Faught and S.R. Moran. 97 pp.

DESCRIPTION: This report describes the premining geologic conditions in the Battle River coal mining area including the geology as well as the groundwater flow patterns, and the groundwater quality of a sequence of several water-bearing formations extending from the surface to a depth of about 100 metres.

** 36. RRTAC 87-10: Soil Survey of the Plains Hydrology and Reclamation Project - Battle River Project Area. T.M. Macyk and A.H. MacLean. 62 pp. plus maps.

DESCRIPTION: The report evaluates the capability of post-mining landscapes and assesses the changes in capability as a result of mining, in the Battle River mining area. Detailed soils information is provided in the report for lands

** 37. RRTAC 87-11: Geology of the Highvale Study Site: Plains Hydrology and Reclamation Project. A. Maslowski-Schutze. 78 pp.

DESCRIPTION: The report is one of a series that describes the geology, soils and groundwater conditions at the Highvale Coal Mine study site. The purpose of the study was to establish a summary of site geology to a level of detail necessary to provide a framework for studies of hydrogeology and reclamation.

** 38. RRTAC 87-12: Premining Groundwater Conditions at the Highvale Site. M.R. Trudell and R. Faught. 83 pp.

DESCRIPTION: This report presents a detailed discussion of the premining flow patterns, hydraulic properties, and isotopic and hydrochemical characteristics of five layers within the Paskapoo Geological Formation, the underlying sandstone beds of the Upper Horseshoe Canyon Formation, and the surficial glacial drift.

* 39. RRTAC 87-13: An Agricultural Capability Rating System for Reconstructed Soils. T.M. Macyk. 27 pp.

DESCRIPTION: This report provides the rationale and a system for assessing the agricultural capability of reconstructed soils. Data on the properties of the soils used in this report are provided in RRTAC 86-2.

** 40. RRTAC 88-1: Eccles, T.R., R.E. Salter and J.E. Green. A Proposed Evaluation System for Wildlife Habitat Reclamation in the Mountains and Foothills Biomes of Alberta: Proposed Methodology and Assessment Handbook. 101 pp. plus appendix.

DESCRIPTION: The report focuses on the development of guidelines and procedures for the assessment of reclaimed wildlife habitat in the Mountains and Foothills regions of Alberta. The technical section provides background documentation including a discussion of reclamation planning, a listing of reclamation habitats and associated key wildlife species, conditions required for development, recommended revegetation species, suitable reclamation techniques, a description of the recommended assessment techniques and a glossary of basic terminology. The assessment handbook section contains basic information necessary for evaluating wildlife habitat reclamation, including assessment scoresheets for 15 different reclamation habitats, standard methodologies for measuring habitat variables used as assessment criteria, and minimum requirements for certification. This handbook is intended as a field manual that could potentially be used by site operators and reclamation officers.

Available from: Publication Services
Queen's Printer
11510 Kingsway Avenue
Edmonton, Alberta T5G 2Y5

* A $5.00 fee is charged for handling and postage.
** A $10.00 fee is charged for handling and postage.
*** A $20.00 fee is charged for handling and postage.
N/A Not available for purchase but available for review at the Alberta Environment Library, 14th Floor, 9820-106 Street, Edmonton, Alberta T5K 2J6.

TABLE OF CONTENTS

Page

PREFACE xvi

ACKNOWLEDGEMENTS xix

Report 1: CHEMISTRY OF GROUNDWATER IN MINE SPOIL, CENTRAL ALBERTA 1

Report 2: IMPACTS OF SURFACE MINING ON CHEMICAL QUALITY OF STREAMS IN THE BATTLE RIVER MINING AREA 108

PREFACE

This volume is part of a series of reports that presents the findings of the Plains Hydrology and Reclamation Project (PHRP), an interdisciplinary study that focuses primarily on hydrologic aspects of reclamation of surface coal mines in the Plains of Alberta. This research has been conducted by the Alberta Research Council, as part of the Alberta Government's Reclamation Research Program. The program is managed by the Land Conservation and Reclamation Council and is supported by the Heritage Trust Fund.

The focus of the PHRP is to develop a predictive framework that will permit projection of success for reclamation and impact of mining on water resources on a long-term basis. The predictive framework is based on an understanding of processes acting within the landscape so that, in the future, mine sites that are not totally analogous to those that have been studied can be evaluated as well.

The project involves a holistic approach to reclamation by integration of studies of geology, hydrogeology, and soils, not only in the proposed mining area, but also in the adjoining unmined areas. This approach permits the assessment of impacts and of long-term performance, not only in reclaimed areas, but also in the surrounding area.

The research of the PHRP has been directed toward the following two major objectives and eight subobjectives:

Objective A

To evaluate the potential for reclamation of lands to be surface mined. The focus is on features of the landscape that make it productive in a broad sense not restricted to revegetation. This objective was organized into five subobjectives.

1. To assess and evaluate the potential for long-term degradation of reclaimed soils through salt buildup.
2. To assess and evaluate the effectiveness of topographic modification and selective placement of

materials to mitigate deleterious impacts on chemical quality of groundwater.

3. To assess the availability of water supply in or beneath cast overburden to support post-mining land use, including both quantity and quality considerations.
4. To evaluate the productivity potential (capability) of post-mining landscapes and the significance of changes in capability as a result of mining.
5. To assess and evaluate limitations to post-mining land use posed by physical instability of cast overburden.

Objective B

To evaluate the long-term impact of mining and reclamation on water quantity and quality. This objective was organized into three subobjectives.

1. To assess and evaluate the long-term alteration of quality of groundwater in cast overburden and surface water fed from mine spoil as a result of the generation of weathering products.
2. To assess and evaluate infiltration, groundwater recharge, and groundwater-surface water interactions within cast overburden.
3. To characterize the groundwater chemistry generated within cast overburden.

Studies directed at these objectives began in 1979 at the Battle River site in east-central Alberta. Work began in 1982 at a second study area at Highvale Mine south of Lake Wabamun.

This volume of reports first characterizes the chemistry of spoil groundwater (Subobjective B-3) and then examines the impacts of the spoil groundwater on surface water (Subobjective B-1). The impact of degraded spoil groundwater quality on adjacent natural aquifers is discussed in a separate report in this series entitled 'Potential Contamination of Shallow Aquifers by Surface Mining of Coal.'

The first report 'Chemistry of Groundwater in Mine Spoil, Central Alberta' is primarily descriptive, although comparisons are included between premining and post-mining groundwater quality, as are comparisons of groundwater chemistry in spoil among different mines and mining areas in central Alberta. Included in this characterization of spoil groundwater chemistry are the following types of constituents: Major ionic species, total dissolved solids, minor constituents (iron and sulfide), and nine trace elements.

The second report in this volume 'Impacts of Surface Mining of Chemical Quality of Streams in the Battle River Mining Area', deals with the latter part of Subobjective B-1, that is the alteration of surface water quality by water from mine spoil. The focus of this report is on groundwater discharge from premining aquifers and mine spoil to surface streams. Surface runoff from mined lands was not considered because drainage patterns in the reclaimed areas are generally poorly developed, and are in all likelihood providing very little runoff to the Battle River, although the amount of this runoff has not been quantified. Runoff water in the reclaimed lands, as characterized by pond water chemistry, is about two to three times more saline than water in the Battle River. However, the area of reclaimed lands relative to the area of the Battle River drainage basin is extremely small, therefore the contribution of runoff from reclaimed lands to water quality degradation in the Battle River is expected to be negligible.

ACKNOWLEDGEMENTS

The Plains Hydrology and Reclamation Project was sponsored by the Reclamation Research Technical Advisory Committee of the Alberta Land Conservation and Reclamation Council, with financial support from the Alberta Heritage Trust Fund. Alberta Power Limited, Luscar Limited, and Manalta Coal Limited, aided the study by providing both available data and access to lands for the research work.

Report 1: CHEMISTRY OF GROUNDWATER IN MINE SPOIL, CENTRAL ALBERTA

by

MARK R. TRUDEL

ROBERT L. FAUGHT

STEPHEN R. MORAN

Terrain Sciences Department
Alberta Research Council

Prepared for

The Plains Coal Reclamation Research Program

of

THE LAND CONSERVATION AND RECLAMATION COUNCIL

(Reclamation Research Technical Advisory Committee)

1988

TABLE OF CONTENTS

Page

LIST OF TABLES 3

LIST OF FIGURES 5

ABSTRACT 9

1. INTRODUCTION 13

2. WELL SAMPLING PROCEDURES 16

3. MAJOR ION CHEMISTRY 17
3.1 Diplomat Mine 22
3.2 Vesta Mine 28
3.3 Highvale Mine 34
3.4 Whitewood Mine 39
3.5 Discussion 44

4. CHANGES IN MAJOR ION CHEMISTRY OF GROUNDWATER: SPOIL VERSUS UNMINED ... 47
4.1 Diplomat Mine 50
4.2 Vesta Mine 50
4.3 Highvale Mine 56
4.4 Whitewood Mine 66

5. SEASONAL VARIATION IN MAJOR ION CHEMISTRY 67
5.1 Diplomat Mine 68
5.2 Vesta Mine 72
5.3 Highvale Mine 76

6. TRACE ELEMENT COMPOSITION OF SPOIL GROUNDWATER 81
6.1 Battle River Mining Area 81
6.2 Lake Wabamun Mining Area 92
6.3 Intersite Comparisons 103

7. SUMMARY 104

8. REFERENCES CITED 107

LIST OF TABLES

Page

1. Summary of Spoil Groundwater Chemical Characteristics - Central Alberta 18
2. Diplomat Mine Spoil - Major Ion Chemistry 23
3. Summary of Major Ionic Constituents in Spoil Groundwater, Diplomat Mine 26
4. Vesta Mine Spoil - Major Ion Chemistry 29
5. Summary of Major Ionic Constituents in Spoil Groundwater, Vesta Mine 32
6. Highvale Mine Spoil - Major Ion Chemistry 35
7. Summary of Major Ionic Constituents in Spoil Groundwater, Highvale Mine (Pit 01) 37
8. Major Ion Chemistry - Whitewood Spoil Groundwater 40
9. Summary of Major Ionic Constituents of Spoil Groundwater, Whitewood Mine 41
10. Summary of Spoil Groundwater Chemical Characteristics - Central Alberta 48
11. Battle River Bed - Major Ion Chemistry 55
12. Highvale Overburden Sandstone - Major Ion Chemistry 65
13. Summary of Trace Element Characteristics 82
14. Diplomat Mine Spoil - Trace Element Analyses 83
15. Vesta Mine Spoil - Trace Element Analyses 84
16. Battle River Bed - Trace Element Analyses 85
17. Summary of Trace Element Analyses, Battle River Mining Area 86
18. Diplomat Mine Spoil - Iron and Sulfide Analyses 89
19. Vesta Mine Spoil - Iron and Sulfide Analyses 90
20. Battle River Bed - Iron and Sulfide Analyses 91

continued . . .

LIST OF TABLES (CONCLUDED)

Page

21. Highvale Spoil - Trace Element Analyses 93

22. Highvale Overburden Sandstone - Trace Element Analyses ... 94

23. Whitewood Spoil - Trace Element Analyses 95

24. Summary of Trace Element Analyses, Lake Wabamun 96

25. Highvale Mine Spoil - Iron and Sulfide Analyses 100

26. Highvale Overburden Sandstone - Iron and Sulfide Analyses 101

27. Whitewood Mine Spoil - Iron and Sulfide Analyses 102

LIST OF FIGURES

Page

1. Locations of the Plains Hydrology and Reclamation Project Study Areas 14

2. Graphical Representation of Mean and Standard Deviation of Post-Mining Sodium and Sulfate Concentrations, the Plains Hydrology and Reclamation Project Study Sites 19

3. Graphical Representation of Mean and Standard Deviation of Calcium and Magnesium Concentrations, the Plains Hydrology and Reclamation Project Study Sites 20

4. Graphical Representation of Mean and Standard Deviation of Total Dissolved Solids Concentrations, the Plains Hydrology and Reclamation Project Study Sites 21

5. Piper Trilinear Diagram of Spoil Groundwater Composition, Diplomat Mine 27

6. Piper Trilinear Diagram of Spoil Groundwater Composition, Vesta Mine 33

7. Piper Trilinear Diagram of Spoil Groundwater Composition, Highvale Mine 38

8. Piper Trilinear Diagram of Spoil Groundwater Composition, Whitewood Mine. Research Council Samples Only 42

9. Comparison of Spoil Groundwater Salinity and Premining Groundwater Salinity at the Plains Hydrology and Reclamation Project Study Mine Sites 49

10. Histogram of Total Dissolved Solids Concentration for Diplomat Spoil and the Battle River Bed 51

11. Histogram of Na^+ Concentration for Diplomat Spoil and the Battle River Bed 51

12. Histogram of Ca^{2+} Concentration for Diplomat Spoil and the Battle River Bed 52

13. Histogram of Mg^{2+} Concentration for Diplomat Spoil and the Battle River Bed 52

14. Histogram of SO_4^{2-} Concentration for Diplomat Spoil and the Battle River Bed 53

continued . . .

LIST OF FIGURES (CONTINUED)

Page

15. Histogram of HCO_3^- Concentration for Diplomat Spoil and the Battle River Bed 53

16. Histogram of Cl^- Concentration for Diplomat Spoil and the Battle River Bed 54

17. Histogram of K^+ Concentration for Diplomat Spoil and the Battle River Bed 54

18. Histogram of Total Dissolved Solids Concentration for Vesta Spoil and the Battle River Bed 57

19. Histogram of Na^+ Concentration for Vesta Spoil and the Battle River Bed 57

20. Histogram of Ca^{2+} Concentration for Vesta Spoil and the Battle River Bed 58

21. Histogram of Mg^{2+} Concentration for Vesta Spoil and the Battle River Bed 58

22. Histogram of SO_4^{2-} Concentration for Vesta Spoil and the Battle River Bed 59

23. Histogram of HCO_3^- Concentration for Vesta Spoil and the Battle River Bed 59

24. Histogram of Cl^- Concentration for Vesta Spoil and the Battle River Bed 60

25. Histogram of K^+ Concentration for Vesta Spoil and the Battle River Bed 60

26. Histogram of Total Dissolved Solids Concentration for Highvale Spoil and the Highvale Overburden Sandstone 61

27. Histogram of Na^+ Concentration for Highvale Spoil and the Highvale Overburden Sandstone 61

28. Histogram of Ca^{2+} Concentration for Highvale Spoil and the Highvale Overburden Sandstone 62

29. Histogram of Mg^{2+} Concentration for Highvale Spoil and the Highvale Overburden Sandstone 62

continued . . .

LIST OF FIGURES (CONTINUED)

Page

30. Histogram of SO_4^{2-} Concentration for Highvale Spoil and the Highvale Overburden Sandstone 63

31. Histogram of HCO_3^- Concentration for Highvale Spoil and the Highvale Overburden Sandstone 63

32. Histogram of K^+ Concentration for Highvale Spoil and the Highvale Overburden Sandstone 64

33. Histogram of Cl^- Concentration for Highvale Spoil and the Highvale Overburden Sandstone 64

34. Concentration versus Time for Piezometer 37-2, Diplomat Spoil Groundwater 69

35. Concentration versus Time for Piezometer 39-3, Diplomat Spoil Groundwater 69

36. Concentration versus Time for Piezometer 40-3, Diplomat Spoil Groundwater 70

37. Concentration versus Time for Piezometer 38-1, Diplomat Spoil Groundwater 70

38. Concentration versus Time for Piezometer 41-1, Diplomat Spoil Groundwater 71

39. Concentration versus Time for Piezometer 40-2, Diplomat Spoil Groundwater 71

40. Concentration versus Time for Piezometer 43-1, Vesta Spoil Groundwater 73

41. Concentration versus Time for Piezometer 52-1, Vesta Spoil Groundwater 73

42. Concentration versus Time for Piezometer 53-1, Vesta Spoil Groundwater 74

43. Concentration versus Time for Piezometer 53-4, Vesta Spoil Groundwater 74

44. Concentration versus Time for Piezometer 54-3, Vesta Spoil Groundwater 75

continued . . .

LIST OF FIGURES (CONCLUDED)

Page

45. Concentration versus Time for Piezometer 56-1, Vesta Spoil Groundwater 75

46. Concentration versus Time for Piezometer 6-3, Highvale Spoil Groundwater 77

47. Concentration versus Time for Piezometer 8-4, Highvale Spoil Groundwater 77

48. Concentration versus Time for Piezometer 9-2, Highvale Spoil Groundwater 78

49. Concentration versus Time for Piezometer 10-2, Highvale Spoil Groundwater 78

50. Concentration versus Time for Piezometer 7-1, Highvale Spoil Groundwater 79

51. Concentration versus Time for Piezometer 12-1, Highvale Spoil Groundwater 79

ABSTRACT

This report describes the chemical makeup of spoil groundwater at four mines in the Plains of Alberta. Diplomat and Vesta Mines are located in the Battle River mining area, 200 km southeast of Edmonton within the Lower Horseshoe Canyon Coal Zone; Highvale and Whitewood Mines are located in the Lake Wabamun mining area, 100 km west of Edmonton within the Ardley Coal Zone.

In this report, the chemical characteristics of the spoil groundwater for each mine are compared to those of the principal premining aquifer that is disrupted by surface mining. This presentation highlights the nature and magnitude of changes in groundwater chemistry resulting from mining. In the Battle River mining area, the Battle River Bed, the coal seam exploited at Diplomat and Vesta Mines, is the main aquifer within the zone disrupted by mining. In the Highvale Mine area, the main premining aquifer is the sandstone overburden of the Paskapoo Formation.

The groundwater in mine spoil is, in virtually all cases, more saline than the premining groundwater. In addition, it commonly is of significantly different composition than that prior to mining. Specific findings are as follows:

1. Major ion chemistry of spoil groundwater at all four mines studied is characterized by increased salinity and changed composition relative to premining aquifers. Salinity increases ranged from 2.4 to 5.9 times the premining levels. Sodium and sulfate account for the major increase in most areas, although calcium and magnesium are significantly increased at Diplomat and Vesta Mines in the Battle River mining area.
2. Major ion chemistry in spoil at Diplomat and Vesta Mines is fundamentally similar with only sodium and sulfate concentrations being significantly higher at Vesta Mine.

3. Major ion chemistry in groundwater in spoil at Diplomat and Vesta Mines at the Battle River mining area is characterized by significantly higher total salinity and significantly greater concentrations of most ionic constituents relative to groundwater in spoil at Highvale and Whitewood Mines at the Lake Wabamun mining area.
4. It is not known whether differences in major ion chemistry between the Battle River and Lake Wabamun mining area reflect a dominance of climatically controlled hydrologic factors or geological differences between the overburden in the two areas. As a consequence, it is not possible to predict whether mines in the southern part of the Ardley Coal Zone near Red Deer, for example, would be expected to contain spoil groundwater more similar in composition to Diplomat and Vesta Mines or to Highvale Mine.
5. Seasonal fluctuations in water chemistry display a generally consistent pattern at the Battle River mining area. Salinity in both water-table wells and at the base of the spoil is the lowest in April, increases to a maximum during the summer and fall and, in most wells, decreases in December or January. The maximum salinity is generally from 7 to 25% higher than the minimum. In addition to this pattern, some water-table wells display significant decreases in salinity related to recharge from individual large rainstorms.
6. No clear pattern of chemical fluctuations has emerged from wells at Highvale Mine.
7. The cause of much of the seasonal variation in spoil-water chemistry is not understood.
8. No clear pattern is yet evident in long-term trends in water chemistry. Some wells display a progressive

decrease in salinity over the four-year record of observation, whereas others have remained essentially constant.

9. In the Battle River mining area, arsenic, boron, cobalt, copper, and lead were widely detected in groundwater samples from spoil at Diplomat and Vesta Mines, as well as from the unmined Battle River Bed aquifer, however, the recommended concentration limit was rarely exceeded. Mercury was not detected in any of the groundwater samples from the Battle River mining area. Selenium and antimony were only rarely detected. Cadmium was widely detected in samples from both the Battle River Bed and Vesta Mine spoil. Six out of fourteen samples from Diplomat Mine exceeded the crop application limit for boron. The recommended limits for cobalt and boron were each exceeded once in samples from Vesta Mine. One sample from the Battle River Bed exceeded the recommended limit for antimony. In the Lake Wabamun mining area, arsenic, boron, cobalt, copper, and lead were widely detected in groundwater samples from the spoil of Pit 01 of Highvale Mine, the unmined overburden at Highvale Mine, and the spoil at Whitewood Mine, but the recommended concentration limits were rarely exceeded. Mercury was not detected in any of the groundwater samples from the Lake Wabamun mining area. Selenium and antimony were rarely detected. Cadmium was detected in one-half of the samples from Whitewood Mine and one-quarter of the samples from Highvale Mine, but not detected in samples from the unmined overburden. In samples from Pit 01 of Highvale Mine, only one groundwater sample from the spoil exceeded the recommended limit for arsenic. One sample from an ash disposal area exceeded the recommended limit for

arsenic, selenium, and antimony. None of the samples from the unmined overburden exceeded any of the recommended maximum concentrations. One sample out of ten analysed from Whitewood exceeded the recommended limit for cobalt.

1. INTRODUCTION

The purpose of this report is to describe the chemical makeup of spoil groundwater at four mines in the Plains region of Alberta. Diplomat and Vesta Mines are located in the Battle River mining area (Figure 1) within the Lower Horseshoe Canyon Coal Zone; Highvale and Whitewood Mines are located in the Lake Wabamun mining area (Figure 1) within the Ardley Coal Zone.

The characterization of spoil groundwater chemistry is based on the sampling and analyses of groundwater from piezometers installed in reclaimed areas. Forty-three samples were collected from 23 piezometers at Vesta Mine, and 54 samples were collected from 32 piezometers at Diplomat Mine. At Highvale Mine, 29 samples were collected from 13 piezometers installed in the reclaimed area at Pit 01. Eleven samples were also collected from piezometers installed in spoil at Whitewood Mine in the Lake Wabamun mining area (Figure 1), to augment a study of that site conducted by Alberta Environment (1980).

At Diplomat Mine, the overburden that makes up the mine spoil is almost entirely glacial drift, mainly calcareous till with minor lenses of sand. At Vesta Mine, the overburden is predominantly bedrock shale, siltstone, and sandstone of the Lower Horseshoe Canyon Formation (Late Cretaceous). The bedrock at Vesta Mine characteristically has a very high sodium montmorillonite content. Glacial drift, primarily till, ranging in thickness from 0 to 7 m, overlies the bedrock at Vesta Mine. At Highvale Mine, the bedrock overburden is primarily sandstone, with a lesser proportion of shale and siltstone, of the Paskapoo Formation (Late Cretaceous-Paleocene). Silt, clay, and till ranging in thickness from less than 1 to 6 m overlie the bedrock overburden in the Highvale Mine area. At Whitewood Mine, the overburden is made up mainly of sand and gravel, with some till and bedrock sandstone of the Paskapoo Formation.

In this report, the chemical characteristics of the spoil groundwater for each mine are compared to those of the principal premining aquifer that is disrupted by surface mining. This

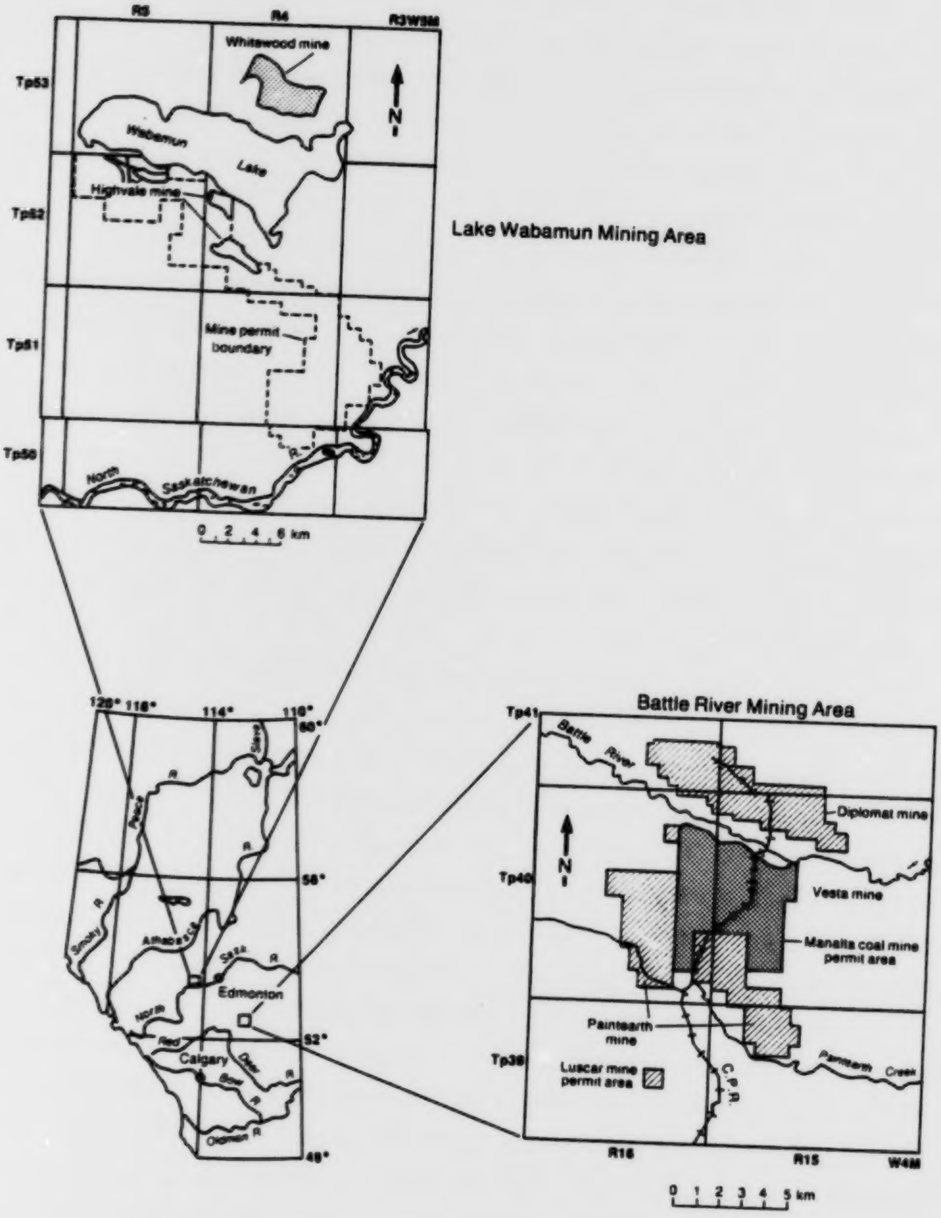

R5
R4
R3W5M
Whitewood mine
Tp53
N
Wabamun
Lake
Highvale mine
Tp52
Lake Wabamun Mining Area
Tp51
Mine permit boundary
Tp50
North
Saskatchewan
R.
0 2 4 6 km
120° 118°
114°
110°
60°
Slave
R
Peace
R
56°
Smoky
R
Athabasca
Sask
R
Edmonton
North
Red
Calgary
Deer
Bow
R
R
Oldman R
52°
49°
Battle River Mining Area
Tp41
Battle
River
Diplomat mine
N
Tp40
Vesta mine
Manalta coal mine permit area
Paintearth mine
Tp39
Luscar mine permit area
C.P.R.
Paintearth
Creek
R16
R15
W4M
0 1 2 3 4 5 km

Figure 1. Locations of the Plains Hydrology and Reclamation Project study areas.

presentation highlights the nature and magnitude of changes in groundwater chemistry resulting from mining. In the Battle River mining area the Battle River Bed, the coal seam exploited at Diplomat and Vesta Mines, is the main aquifer within the zone disrupted by mining (Trudell et al. 1986). In the Highvale Mine area, the main premining aquifer is the sandstone overburden of the Paskapoo Formation (Montreal Engineering 1978; Trudell 1986). At the Whitewood Mine, overburden sandstone (Paskapoo Formation) and sand and gravel are significant premining aquifers (Montreal Engineering 1979). Where statistical comparisons have been made, a two-tailed t-test has been used with a 95% level of significance.

The groundwater in mine spoil is, in virtually all cases, more saline than the premining groundwater. In addition, it commonly is of significantly different composition than prior to mining. Two processes account for these differences: (1) A significant amount of secondary salt that was concentrated in the lower part of the soil profile prior to mining is solubilized as the mine spoil resaturates following reclamation. (2) Rock material that was originally beneath the water table is exposed to atmospheric weathering processes as a result of mining. This enables the conversion of some insoluble minerals into readily soluble oxidation products.

2. WELL SAMPLING PROCEDURES

Groundwater samples were obtained from the spoil monitoring wells using either a peristaltic pump or a bailer. The peristaltic pump could be used only where the depth to water was less than about 6 m. A PVC bailer was used for wells having a water level greater than 6 m below ground surface. Samples were centrifuged and then filtered through a 0.45 micron filter membrane using a peristaltic pump. The samples for major ion and trace element analyses were stored in polyethylene bottles that had been cleaned by thoroughly rinsing with 10% nitric acid, distilled water and then with the sample. The sample for trace element analyses was preserved by adjusting the pH to approximately 2.0 using concentrated nitric acid. The ^{3}H, ^{18}O, ^{2}H aliquots were stored in 20 mL glass vials that were completely filled with sample to eliminate any entrapped air bubbles.

Measurements of temperature, dissolved oxygen, pH, alkalinity, specific conductance, turbidity, total iron, and sulfide were made in the field. Dissolved oxygen and temperature were measured directly in the well using a YSI Model 57 meter with a 60 m attached cable and probe. The pH was measured on a filtered sample with a Markson Model 88 meter and combination pH/reference electrode. The alkalinity was determined on a filtered sample by titration with standardized HCl. Conductivity was measured on a filtered sample using a YSI Model 33 meter with a plastic conductivity cell and thermistor temperature sensor housed in a single body. Turbidity, total iron and sulfide were measured using a Hach Model DR/2 spectrophotometer.

3. MAJOR ION CHEMISTRY

The chemical characteristics of groundwater in reclaimed coal mine spoil studied at four sites in two mining areas in central Alberta show general similarities as well as some marked differences (Table 1).

The groundwater chemistry in spoil at two mine sites in the Battle River mining area, Diplomat and Vesta Mines, is strikingly similar. Although the water in Vesta spoil is appreciably more saline than that from Diplomat spoil, the only constituents that are significantly different at the 90% level (t-test) are sodium and sulfate (Figures 2 and 3). The difference in total dissolved solids (TDS) values is not significant because of the large scatter in values (Figure 4).

The same general similarity between spoil groundwater is not evident for the two mines in the Lake Wabamun mining area (Table 1, Figures 2, 3, and 4). With the exception of potassium and bicarbonate, every constituent, as well as the TDS content, of groundwater from Whitewood Mine is significantly different from groundwater at Highvale Mine at the 95% level.

Examination of Table 1 and Figures 2, 3, and 4 suggest that the water at the Battle River site is different from that at the Lake Wabamun site. These differences are significant at least at the 90% level for TDS, Ca^{2+}, Mg^{2+}, SO_4^{2-}, and HCO_3^- between Diplomat and Highvale Mines, and at least the 95% level for TDS, Mg^{2+}, Na^+, K^+, SO_4^{2-}, and Cl^- between Diplomat and Whitewood Mines. Groundwater chemistry at Vesta Mine is significantly different from that at Highvale Mine, at least at the 95% level for all constituents except K^+, HCO_3^-, and Cl^-; only Ca^{2+} and HCO_3^- are not significantly different at the 90% level between Vesta and Whitewood Mines.

The remainder of this section discusses in detail, the chemistry of groundwater in individual mine sites.

Table 1. Summary of spoil groundwater chemical characteristics (mg/L) - central Alberta.

Mine	Coal Zone	Nature of Overburden	Spoil Groundwater Chemistry							
			TDS	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	SO_4^{2-}	HCO_3^{-}	Cl^{-}
			$\bar{X}$ σ	$\bar{X}$ σ	$\bar{X}$ σ	$\bar{X}$ σ	$\bar{X}$ σ	$\bar{X}$ σ	$\bar{X}$ σ	$\bar{X}$ σ
Whitewood	Ardley	Sand and Gravel	1395	222	58.6	52.2	6.0	178	841	2.0
		and Paskapoo Formation	330	38.4	19.4	29.7	2.5	119	276	2.1
Highvale	Ardley	Paskapoo Formation	3668	109	26.6	934	11.2	1073	1451	11.6
		and Glacial Drift	1461	102	30.1	465	15.4	988	540	11.7
Diplomat	Lower Horseshoe	Glacial Till	5708	381	174	1114	14.9	3094	900	11.4
	Canyon Formation		1835	88.4	136	493	4.7	1149	259	10.5
Vesta	Lower Horseshoe	Horseshoe Canyon Formation	7443	280	141	1749	15.2	5186	1045	10.8
	Canyon Formation	and Glacial Till	2644	123	89.8	685	6.0	1820	276	8.4

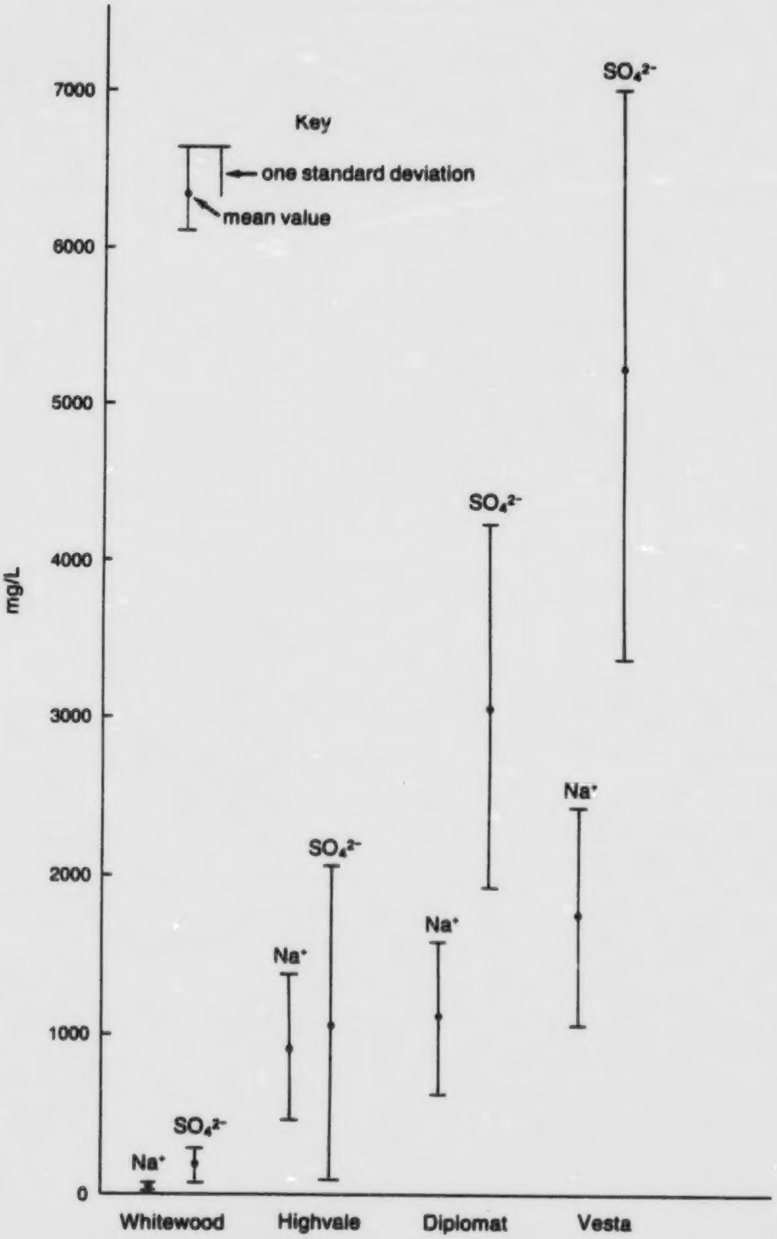


Figure 2. Graphical representation of mean and standard deviation of post-mining sodium and sulfate concentrations, the Plains Hydrology and Reclamation Project study sites.

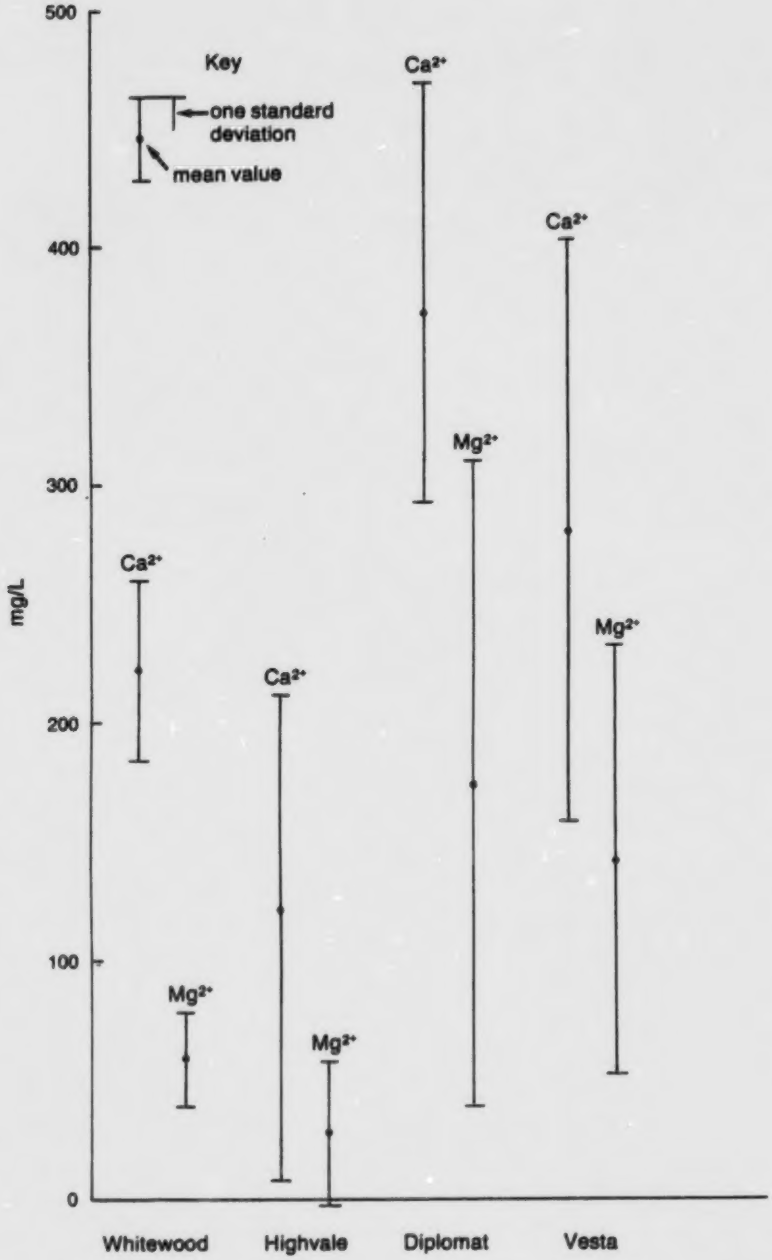


Figure 3. Graphical representation of mean and standard deviation of calcium and magnesium concentrations, the Plains Hydrology and Reclamation Project study sites.

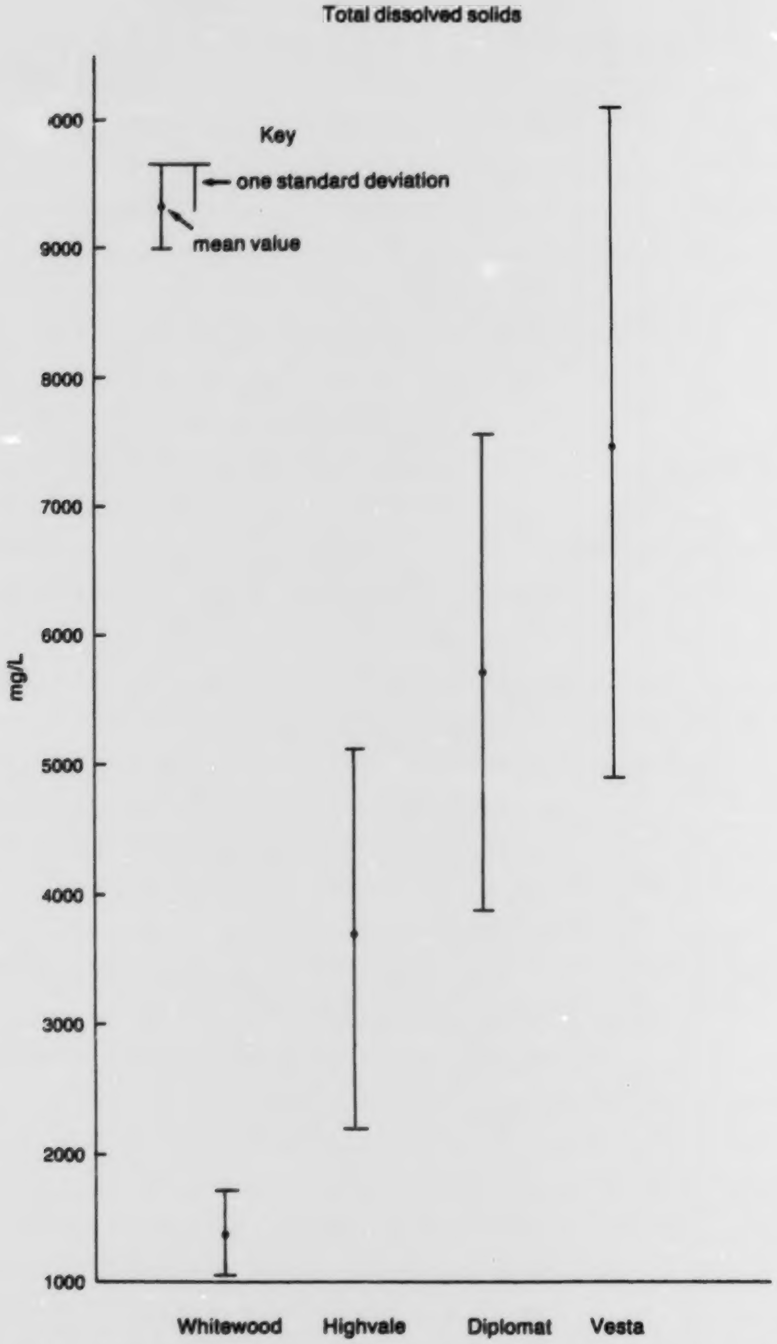


Figure 4. Graphical representation of mean and standard deviation of total dissolved solids concentrations, the Plains Hydrology and Reclamation Project study sites.

3.1 DIPLOMAT MINE

Groundwater in the spoil at Diplomat Mine is characterized by high TDS with sodium and sulfate as the dominant ionic constituents, although calcium and bicarbonate are also significant components. Table 2 is a listing of major ion analyses of groundwater from the spoil at Diplomat Mine. Table 3 summarizes these data for the entire mine site.

The spoil groundwater at Diplomat Mine is 2.9 times more saline than water from the Battle River Bed. Sulfate concentrations show the greatest increase (73.8 times) in spoil groundwater over premining groundwater, although significant increases in Ca^{2+} and Mg^{2+} are also observed (11.0 times and 47.0 times the premining concentration, respectively). The relative changes between premining and spoil groundwater chemistry are discussed in detail in Section 4 of this report.

As illustrated on a Piper trilinear diagram (Figure 5), sodium plus potassium make up from 20 to 90% of the cation component of the spoil groundwater, although the contribution from potassium is negligible. Calcium is a secondary cation in the spoil groundwater at Diplomat Mine, although in some cases calcium forms the dominant cation. From 0 to 60% of the cation fraction consists of calcium, however, calcium generally makes up from 10 to 30% of the cation component (Figure 5). Magnesium follows a trend very similar to that of calcium, in most cases making up from 5 to 25% of the cationic composition, although the overall range of percentages extends from 0 to 40% (Figure 5).

Sulfate is the dominant anion in the spoil groundwater at Diplomat Mine, with bicarbonate as the secondary anion; the contribution of chloride is negligible. Sulfate makes up from 60 to 95% of the anionic component of the spoil groundwater, with most samples having between 75 and 90% sulfate (Figure 5). The typically high sulfate concentrations, (Tables 2 and 3) combined with significant calcium concentrations, give rise to conditions of saturation with respect to gypsum as a commonplace occurrence in the

Table 2. Diplomat Mine spoil - major ion chemistry (all values in mg/L).

Sample ID	Date	Ca^{2+}	$\overline{X}$	Mg^{2+}	$\overline{X}$	Na^{+}	$\overline{X}$	K^{+}	$\overline{X}$	CO$_3^{2-}$	$\overline{X}$	HCO$_3^{-}$	$\overline{X}$	SO$_4^{2-}$	$\overline{X}$	NO$_3^{-}$	$\overline{X}$	Cl^{-}	$\overline{X}$	TDS	$\overline{X}$
37-1-1	01/06/81	351	416[a]	250	259	1125	1116	19.0	19.0	0	0	951	905	3300	3518	4.0	3.1	17.0	15	6037	6420
37-1-2	15/10/81	382		244		1119		20.0		0		1022		3420		2.5		17.0		6694	
37-1-3	28/10/82	516		284		1104		19.0		0		741		3833		2.8		10.0		6530	
37-2-1	04/07/80	335	341	82	86	1175	1181	10.0	9.0	0	0	1107	937	2308	2670	23.0	6.8	10.0	7	5066	5166
37-2-2	28/04/81	338		81		1050		10.0		0		821		2300		0.1		6.0		4456	
37-2-3	01/06/81	365		86		1125		9.0		0		913		2280		0.2		4.0		4566	
37-2-4	23/04/82	365		86		1199		9.0		0		913		2965		23.8		8.0		5584	
37-2-5	26/04/83	270		86		1300		8.9		0		690		2790		1.5		4.0		5167	
37-2-6	21/06/83	365		92		1180		9.2		0		994		2865		1.1		8.4		5522	
37-2-7	30/08/83	340		87		1220						990		2835						5419	
37-2-8	28/10/83	370		90		1260		9.7		0		1014		2940		3.7		7.7		5709	
37-2-9	05/01/84	325		88		1120		11.0		0		990		2745		0.7		8.1		5008	
38-1-1	23/07/80	291	295	90	75	935	1037	11.0	10.5	0	0	576	863	2600	2477	1.1	3.6	12.0	7	4528	4773
38-1-2	05/11/81	356		78		1106		12.0		0		883		2880		0.2		8.0		5339	
38-1-3	11/06/82	313		74		1092		10.0		0		935		2574		1.6		6.0		5021	
38-1-4	19/04/83	174		72		1037		10.0		0		505		2385		4.0		7.0		4209	
38-1-5	21/06/83	320		74		985		9.8		0		936		2340		1.2		4.0		4684	
38-1-6	30/08/83	305		71		1060		9.6		0		1026		2370		2.3		6.7		4791	
38-1-7	26/10/83	320		72		1060		10.0		0		1011		2355		15.8		5.9		4864	
38-1-8	05/01/84	280		71		1020		12.0		0		1031		2310		2.2		8.2		4749	
39-1-1	23/07/80	245	304	86	99	1040	1118	14.0	14.75	12	12	493	713	2700	2896	<0.5	1.1	14.0	11	4615	5174
39-1-2	11/06/82	363		112		1195		13.5		0		932		3092		1.7		7.0		5732	
39-2-1	16/10/80	465	443	305	313	1019	1169	21.0	21.5	0	0	983	941	3750	3926	2.6	3.1	35.0	30	6600	6864
39-2-2	26/10/82	420		321		1319		22.0		0		898		4102		3.6		25.0		7128	
39-3-1	28/11/80	476	380	255	238	985	1004	23.0	19.3	0	0	1400	810	2750	3258	0.1	12.0	13.0	8	5914	5729
39-3-2	06/11/81	415		282		1110		21.0		0		974		3950		1.8		13.8		6775	
39-3-3	11/06/82	349		289		1169		21.0		0		912		4018		0.7		10.0		6871	
39-3-4	19/04/83	137		245		1180		17.0		0		220		3240		13.0		9.0		5065	
39-3-5	18/05/83	435		275		1080		19.0		0		1065		3600		7.6		6.0		6504	
39-3-6	21/06/83	475		305		1180		22.0		0		1075		3900		7.3		4.0		6988	
39-3-7	27/07/83	126		52		305		12.0		0		163		1005		5.1		3.5		1675	

continued . . .

Table 2. Continued.

Sample ID	Date	Ca^{2+}	$\bar{X}$	Mg^{2+}	$\bar{X}$	Na^+	$\bar{X}$	K^+	$\bar{X}$	CO_3^{2-}	$\bar{X}$	HCO_3^-	$\bar{X}$	SO_4^{2-}	$\bar{X}$	NO_3^-	$\bar{X}$	Cl^-	$\bar{X}$	TDS	$\bar{X}$
39-3-8	25/08/83	465		199		785		21.0		0		575		3000		16.0		8.3		5005	
39-3-9	30/09/83	535		235		1085		20.0		0		1014		3540		23.0		7.5		6368	
39-3-10	26/10/83	450		240		1100		19.0		0		1087		3480		6.4		5.2		6402	
39-3-11	29/11/83	320		245		1060		17.0		0		426		3360		0.6		4.7		5448	
40-1-1	23/07/80	336	379	242	174	1032	943	15.0	14.0	4.0	4	578	1231	3600	3000	20.5	10.3	18.0	12.0	5839	5766
40-1-2	27/11/80	421		105		854		13.0		0		1883		2400		0.1		6.0		5693	
40-2-1	28/11/80	521	449	273	250	939	914	17.0	15.0	0	0	1833	906	2725	3161	0.1	4.0	8.0	8.6	6329	5716
40-2-2	05/11/81	457		254		875		16.0		0		727		3590		0.3		9.0		5946	
40-2-3	26/10/82	425		239		1010		14.0		0		809		3208		0.9		9.0		5732	
40-2-4	19/04/83	385		235		935		14.0		0		669		2985		2.8		9.0		5251	
40-2-5	22/06/83	470		255		880		15.0		0		801		3300		3.4		8.0		5750	
40-2-6	25/08/83	445		240		885		15.0		0		870		3120		1.2		9.1		5533	
40-2-7	26/10/83	460		245		930		16.0		0		745		3240		22.0		8.4		5683	
40-2-8	05/01/84	425		255		855		16.0		0		805		3120		4.9		8.6		5507	
40-3-1	27/11/80	449	404	153	166	669	713	15.0	16.0	0	0	1317	747	1875	2479	0.1	28.0	6.0	8.7	4493	4572
40-3-2	03/06/82	447		189		862		18.0		0		985		2860		0.8		15.0		5395	
40-3-3	27/04/83	193		170		835		15.0		0		346		2355		7.1		12.0		3942	
40-3-4	18/05/83	465		175		735		16.0		0		1065		2595		28.0		10.0		5104	
40-3-5	22/06/83	500		189		750		16.0		0		956		2685		22.0		12.0		5145	
40-3-6	22/07/83	460		144		575		18.0		0		511		2475		5.7		4.3		4203	
40-3-7	25/08/83	455		154		665		16.0		0		697		2475		7.5		6.4		4472	
40-3-8	30/09/83	480		163		720		17.0		0		757		2565		129.0		8.5		4833	
40-3-9	26/10/83	455		157		685		16.0		0		753		2445		26.0		6.9		4556	
40-3-10	29/11/83	235		173		700		16.0		0		98		2565		11.0		7.3		3819	
40-3-11	05/01/84	300		162		650		15.0		0		737		2370		71.0		7.5		4325	
41-1-1	27/11/80	338	348	79	128	657	621	18.0	15.4	0	0	1433	1000	1075	1845	0.1	8.3	6.0	7.9	3636	3990
41-1-2	05/11/81	406		183		756		17.0		0		982		2740		0.4		8.0		5120	
41-1-3	16/06/82	368		139		609		12.0		0		973		2036		0.8		7.0		4166	
41-1-4	20/04/83	214		119		620		18.0		0		571		1725		0.1		16.5		3294	
41-1-5	22/06/83	375		130		565		18.0		0		1023		1785		1.9		6.0		3921	
41-1-6	24/08/83	370		122		595		15.0		0		998		1800		4.7		7.5		3907	
41-1-7	26/10/83	375		121		595		12.0		0		998		1800		46.0		5.8		3971	
41-1-8	05/01/84	340		130		570		13.0		0		1019		1800		12.0		6.4		3908	
41-2-1	28/11/80	500	479	280	222	1280	1013	25.0	21.0	0	0	2200	1444	2800	2729	0.1	4.95	42.0	24.5	7069	5915
41-2-2	27/10/82	458		163		746		17.0		0		688		2658		9.8		7.0		4760	
41-3-1	16/10/81	440	429	242	308	1212	1350	30.0	26.5	0	0	1222	1271	3730	4148	0.8	3.6	74.0	60.0	6971	7614
41-3-2	16/06/82	418		373		1487		23.0		0		1319		4566		6.4		46.0		8256	

Table 2. Concluded.

Sample ID	Date	Ca^{2+}	$\bar{X}$	Mg^{2+}	$\bar{X}$	Na^{+}	$\bar{X}$	K^{+}	$\bar{X}$	CO_3^{2-}	$\bar{X}$	HCO_3^{-}	$\bar{X}$	SO_4^{2-}	$\bar{X}$	NO_3^{-}	$\bar{X}$	Cl^{-}	$\bar{X}$	TDS	$\bar{X}$
51-1-1	13/11/80	466	299	177	103	2010	1568	22.0	15.0	0	1.2	644	636	5800	4146	<0.5	0.8	36	21	9163	6796
51-1-2	27/10/82	132		29		1125		8.0		1.2		628		2491		1.0		5		4428	
51-2-1	20/10/80	101	263	17	105	1080	1921	7.0	14.5	0	0	546	673	2150	4358	1.3	1.5	4	12	3913	7354
51-2-2	02/11/82	424		193		2761		22.0		0		799		6565		1.6		20		10794	
59-1-1	01/06/83	265		147		189		22.0		0		305		1290		39.0		10		2294	
63-1-1	18/11/82	216		41		1662		10.0		0		1064		3067		1.6		6		6080	
63-2-1	18/11/82	503		133		1096		13.0		0		677		3131		0.7		2		5545	
63-3-1	18/11/82	554		126		646		7.0		0		1280		2107		9.3		5		4821	
64-1-1	29/10/82	312		78		1686		11.0		0		829		3545		2.5		8		6483	
64-2-1	27/10/82	446		153		1417		16.0		0		789		3627		9.0		9		6476	
64-3-1	27/10/82	434		129		1595		13.0		0		982		3673		3.2		8		6854	
64-4-1	02/11/82	426		217		1278		16.0		0		1047		3444		5.2		5		6450	
65-1-1	04/06/82	381		80		1312		10.0		0		1058		3131		0.5		9		5990	
65-2-1	04/06/82	408		258		1391		14.0		0		1009		3798		1.8		11		6909	
65-3-1	03/11/82	323		100		895		13.0		0		523		2386		5.0		10		4270	
66-1-1	09/06/82	314		92		723		15.0		0		757		2263		3.2		7		4192	
66-2-1	10/06/82	526		133		294		12.0		0		639		1947		0.8		2		3571	
66-3-1	10/06/81	457		125		204		11.0		0		645		1640		1.3		2		3100	
66-4-1	10/06/82	320		72		145		8.0		0		588		886		1.8		3		2038	
67-1-1	01/12/82	367		131		1040		11.0		0		1136		2417		2.8		16		5134	
68-1-1	01/06/83	245		110		1294		11.0		0		761		3000		2.8		11		5449	
68-2-1	01/06/83	345		191		1185		16.0		0		725		3360		3.9		13		5853	
68-3-1	01/06/83	290		168		1660		15.0		0		935		3840		0.2		21		6943	
71-2-1	30/11/82	579		233		1207		27.0		0		1289		3452		1.7		7		6813	
71-3-1	01/12/82	411		846		2415		19.0		0		1376		7690		1.6		3		12766	
Mean		381.5		174		1114		14.9		0.49		900		3094		5.4		11.4		5708	
SD		88.4		136.3		493		4.74		2.12		259		1149		7.7		10.5		1835	
N		35		35		35		35		35		35		35		35		35		35	

[a] Symbol: Bracket indicates mean of multiple sampling of one well; $\bar{X}$ = mean; TDS = total dissolved solids; SD = standard deviatiation; N = sample number; 0 = value of zero.

Table 3. Summary of major ionic constituents in spoil groundwater, Diplomat Mine. (Concentrations in mg/L).

	Mean	SD[a]	Range	Common Range
TDS	5875	1607	2038 to 12766	4000 to 8000
Na	1112	450	145 to 2761	600 to 1200
Ca	381	88	101 to 579	300 to 500
Mg	182	129	17 to 846	50 to 250
SO_4	3098	1165	886 to 7690	2500 to 4500
HCO_3	955	355	523 to 2200	700 to 1300

[a] Symbol: SD = standard deviation.

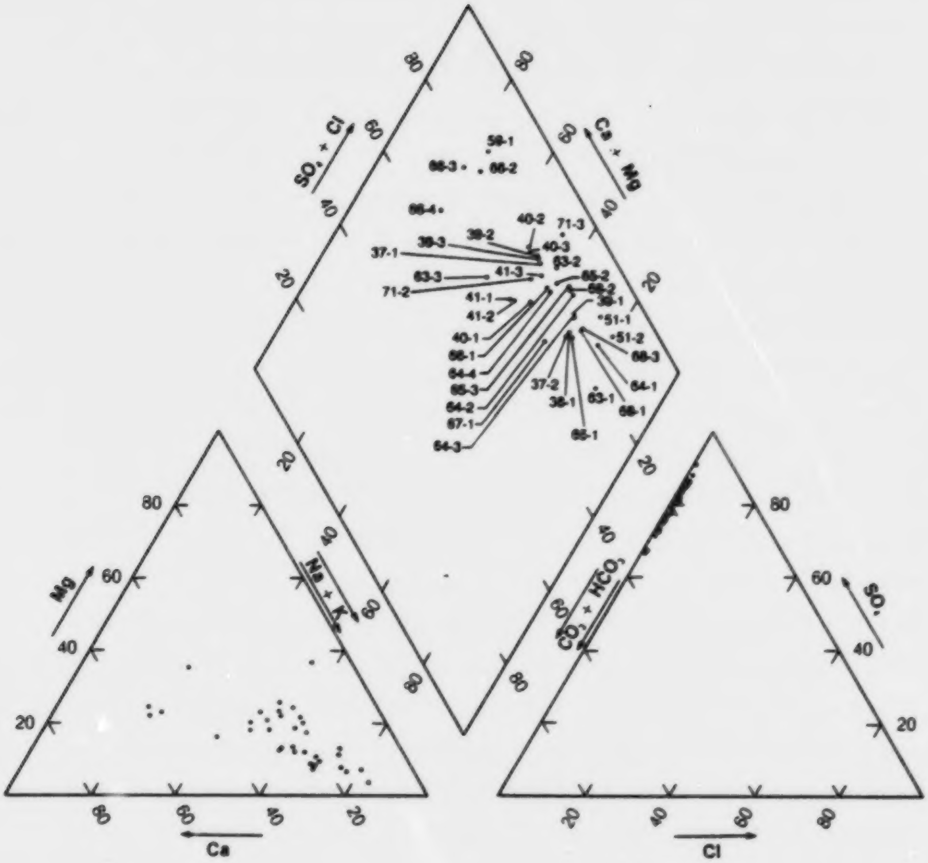


Figure 5. Piper trilinear diagram of spoil groundwater composition, Diplomat Mine.

spoil groundwater at Diplomat Mine. As a percentage of the anionic makeup of the spoil groundwater at Diplomat Mine, bicarbonate is typically between 10 and 25%, although values up to 35% have been measured in some samples (Figure 5).

3.2 VESTA MINE

The composition of spoil groundwater at Vesta Mine, like that at Diplomat Mine, is dominated by sodium and sulfate, and the salinity is characterized by TDS concentrations that are higher than at Diplomat Mine. Calcium and magnesium are also significant cationic constituents of the spoil groundwater at Vesta Mine, and bicarbonate is an important anionic constituent. Table 4 is a listing of major ion analyses of groundwater from the spoil at Vesta Mine. Table 5 summarizes these data for the entire mine site.

The spoil groundwater at Vesta Mine is 3.9 times more saline than groundwater from the Battle River Bed. As at Diplomat Mine, sulfate concentrations in the spoil groundwater show the largest increases, at 124 times the premining level, with other large increases in both Ca^{2+} and Mg^{2+} (8.1 and 38.1 times, respectively). These changes are discussed in more detail in Section 4.

Sodium, the dominant cation in spoil groundwater at Vesta Mine, makes up from 50 to 90% of the cation composition (Figure 6). Potassium, which is included with sodium in the Piper trilinear diagram, is negligible relative to sodium. Both calcium and magnesium are secondary cations in the spoil groundwater at Vesta Mine, making up from zero to 25% of the cation component (Figure 6). It is worthwhile to note that despite the predominantly bedrock composition of the spoil at Vesta Mine, the spoil groundwater has significant levels of both calcium and magnesium, reflecting the influence of small amounts of saline till incorporated within the spoil (Trudell et al. 1983).

Sulfate is the dominant anion in the spoil groundwater at Vesta Mine, with most samples having an anion composition that is from 75 to 95% sulfate (Figure 6). Bicarbonate is the only remaining

Table 4. Vesta Mine spoil - major ion chemistry (all values in mg/L).

Sample ID	Date	Ca^{2+}	$\bar{X}$	Mg^{2+}	$\bar{X}$	Na^{+}	$\bar{X}$	K^{+}	$\bar{X}$	CO_3^{2-}	$\bar{X}$	HCO_3^{-}	$\bar{X}$	SO_4^{2-}	$\bar{X}$	NO_3^{-}	$\bar{X}$	Cl^{-}	$\bar{X}$	TDS	$\bar{X}$
42-1-1	13/08/80	38	152[a]	36.0	66.3	1100	1174	5.5	9.4	26	8.7	1211	1279	1409	1898	29.2	10.2	14.0	9.3	3871	4618
42-1-2	22/07/81	358		129.0		1344		18.3		0		1016		2950		0.8		5.8		5834	
42-1-3	16/06/82	61		34.0		1077		4.3		0		1610		1344		0.7		8.0		4151	
42-2-1	23/07/81	252	306	150.0	130.5	1839	1781	16.8	16.1	0	0	715	894	5140	4514	0.6	5.2	0.0	1.5	8124	7648
42-2-2	19/11/82	360		111.0		1722		15.4		0		1072		3888		9.8		3.0		7171	
42-3-1	22/07/81	82	187	38.7	92.9	1119	1495	5.8	9.1	0	0	1522	1123	1445	3076	0.3	1.7	9.2	4.8	4235	6037
42-3-2	16/07/82	291		147.0		1870		12.4		0		724		4707		3.1		0.4		7838	
43-1-1	23/07/81	316	323	172.0	159.6	1573	1477	12.3	11.4	0	0	1014	1145	4495	3624	0.2	4.9	13.4	10.3	7608	6738
43-1-2	17/06/82	358		190.0		1607		11.8		0		1078		4310		1.1		7.6		7575	
43-1-3	20/04/83	280		169.0		1560		11.0		0		805		3480		13.0		8.0		6242	
43-1-4	16/06/83	360		160.0		1400		11.0		0		1168		3480		1.4		6.0		6596	
43-1-5	31/08/83	315		137.0		1400		10.0		0		1308		3180		0.5		9.6		6242	
43-1-6	01/11/83	330		146.0		1500		11.0		0		1353		3360		1.9		8.8		6721	
43-1-7	06/01/84	305		143.0		1300		13.0		0		1288		3060		16.0		18.6		6184	
43-2-1	23/07/81	90	179	96.0	107.0	2753	2755	21.2	20.9	0	0	899	1126	4260	5051	0.4	5.1	15.5	16.6	8144	9267
43-2-2	22/06/82	268		117.0		2756		20.5		0		1353		5841		9.7		17.6		10390	
52-1-1	01/09/81	26	28.4	2.9	3.4	1331	1375	5.4	4.9	23	6.3	987	1208	2070	1920	0.2	10.5	9.8	7.0	4466	4561
52-1-2	23/06/82	13		3.8		1419		4.2		21		1132		2009		15.1		4.4		4632	
52-1-3	21/04/83	18		3.1		1395		3.5		0		1144		1785		41.0		5.0		4404	
52-1-4	23/06/83	44		3.8		1400		4.5		0		1246		2010		1.3		2.0		4722	
52-1-5	01/09/83	35		3.5		1400		4.7		0		1288		1935		1.5		5.9		4604	
52-1-6	01/11/83	40		3.5		1350		5.2		0		1329		1845		13.0		5.8		4632	
52-1-7	06/01/84	23		3.2		1300		7.0		0		1329		1785		1.5		6.0		4464	
52-2-1	01/09/81	56		12.9		1225		8.3		0		851		2425		1.8		13.0		4602	
52-3-1	01/09/81	322	335	97.0	97.5	1000	1006	14.6	13.3	0	0	627	653	2830	2762	0.2	4.3	6.4	3.2	4916	4885
52-3-2	23/06/82	347		98.0		1006		12.0		0		678		2694		8.3		0.0		4853	
52-4-1	11/02/81	301	305	78.0	78.0	856	897	13.4	12.1	0	0	727	721	2580	2474	0.2	1.2	13.6	9.9	4580	4508
52-4-2	24/06/82	308		78.0		938		10.7		0		714		2368		2.2		6.2		4436	
53-1-1	09/09/81	67		56.0		1638		14.2		25		759		3370		0.4		7.8		5950	
53-1-2	18/06/82	136		96.0		1470		8.1		0		1143		3021		3.3		2.4		5891	
53-1-3	21/04/83	126		106.0		1400		8.0		0		815		2640		39.0		4.0		5109	

Table 4. Continued.

Sample ID	Date	Ca^{2+}	$\bar{x}$	Mg^{2+}	$\bar{x}$	Na^{+}	$\bar{x}$	K^{+}	$\bar{x}$	CO_3^{2-}	$\bar{x}$	HCO_3^{-}	$\bar{x}$	SO_4^{2-}	$\bar{x}$	NO_3^{-}	$\bar{x}$	Cl^{-}	$\bar{x}$	TDS	$\bar{x}$
53-1-4	23/06/83	225	175.6	125.0	107.1	1380	1470	9.7	10.5	0	3.6	1057	979	3000	3099	2.1	8.7	4.0	4.5	5814	5853
53-1-5	01/09/83	240		125.0		1560		11.0		0		1031		3420		8.6		5.1		6337	
53-1-6	01/11/83	210		111.0		1440		9.7		0		1063		3000		4.8		4.0		5854	
53-1-7	10/01/84	225		131.0		1400		13.0		0		986		3240		2.7		3.9		6013	
53-2-1	09/09/81	363	380	241.0	260.0	1394	1407	16.6	14.6	0	0	779	797	4110	4339	0.2	0.7	7.6	4.4	6927	7217
53-2-2	18/06/82	397		279.0		1420		12.6		0		815		4568		1.1		1.2		7506	
53-3-1	10/09/81	386	371	222.0	226.5	1650	1710	17.1	15.1	0	0	783	727	5170	5137	1.6	1.6	4.0	2.2	8249	8204
53-3-2	18/06/82	356		231.0		1769		13.0		0		670		5104		1.6		0.4		8158	
53-4-1	10/09/81	447	415	198.0	223.3	994	1073	15.4	14.1	0	0	871	816.8	3590	3377	0.3	7.7	4.2	2.9	6133	5962
53-4-2	22/06/82	442		248.0		1094		13.5		0		883		3440		0.8		2.6		6137	
53-4-3	21/04/83	355		215.0		1140		13.0		0		664		3240		44.0		3.0		5647	
53-4-4	18/05/83	465		230.0		1040		15.0		0		898		3540		5.5		2.0		6208	
53-4-5	23/06/83	455		230.0		1080		14.0		0		886		3540		3.2		2.0		6221	
53-4-6	27/07/83	430		220.0		1060		14.0		0		914		3420		3.6		2.8		6077	
53-4-7	31/08/83	420		230.0		1160		14.0		0		906		3540		2.7		4.5		6243	
53-4-8	30/09/83	430		220.0		1080		14.0		0		891		3300		6.0		4.3		5958	
53-4-9	01/11/83	405		215.0		1080		13.0		0		918		3240		9.6		3.2		5896	
53-4-10	29/11/83	310		225.0		1040		15.0		0		292		3300		6.1		1.7		5202	
53-4-11	10/01/84	405		225.0		1040		14.0		0		862		3000		2.6		3.1		5864	
53-5-1	11/09/81	409	424	225.0	244.5	1019	1004	15.0	14.2	0	0	887	843	3705	3547	0.3	0.8	4.6	2.8	6282	6095
53-5-2	22/06/82	438		264.0		988		13.3		0		798		3388		1.3		1.0		5907	
54-1-1	14/10/81	17	19.0	3.5	3.3	875	874	4.6	4.6	0	0	1538	1559	595	613	0.2	0.9	14.2	12.3	3057	3101
54-1-2	17/06/82	20		3.0		872		4.5		0		1579		631		1.6		10.4		3145	
54-2-1	15/10/81	382	313	52.0	46.3	2419	2466	22.1	20.9	0	0	1402	1369	5060	5126	0.4	0.7	15.2	13.0	9360	9362
54-2-2	17/06/82	244		40.5		2512		19.6		0		1336		5192		1.0		10.8		9364	
54-3-1	06/11/81	311	241	61.9	50.6	2375	2365	22.9	20.9	0	0	1418	1286	5240	4986	0.2	9.3	12.2	7.0	9451	8741
54-3-2	04/11/82	149		50.0		2839		21.6		0		1418		5301		2.9		0.0		9369	
54-3-3	26/04/83	189		46.0		2340		19.0		0		875		4980		0.3		6.0		8463	
54-3-4	23/06/83	365		54.0		2340		19.0		0		1167		4920		20.0		4.0		8897	
54-3-5	01/09/83	265		46.0		2320		20.0		0		1457		4740		2.8		10.5		8567	
54-3-6	28/10/83	170		50.0		2280		21.0		0		1268		4560		15.0		9.6		8373	
54-3-7	06/01/84	240		46.0		2060		23.0		0		1401		4260		24.0		7.0		8068	

continued . . .

Table 4. Concluded.

Sample ID	Date	Ca^{2+}	$\bar{X}$	Mg^{2+}	$\bar{X}$	Na^{+}	$\bar{X}$	K^{+}	$\bar{X}$	CO_3^{2-}	$\bar{X}$	HCO_3^{-}	$\bar{X}$	SO_4^{2-}	$\bar{X}$	NO_3^{-}	$\bar{X}$	Cl^{-}	$\bar{X}$	TDS	$\bar{X}$
55-1-1	03/08/81	327		253.0		3070		29.6		0		1691		8400		0.6		20.4		13805	
55-2-1	02/08/81	351		274.0		2069		18.3		0		759		5800		0.3		6.2		9293	
55-3-1	02/08/81	373		183.0		1894		18.3		0		971		5770		0.4		15.2		9244	
55-4-1	02/08/81	343		176.0		2650		21.2		0		919		6340		0.5		27.2		10488	
55-5-1	03/08/81	380		276.0		2912		22.5		0		1110		7280		1.9		34.2		12301	
55-6-1	03/08/81	282		97.0		2481		20.4		0		1358		5050		0.4		23.0		9324	
56-1-1	01/09/81	461	442[a]	168.0	211.4	1450	1338	17.9	13.7	0	0	757	900	3930	3862	0.5	9.7	12.6	9.2	6806	6777
56-1-2	04/11/82	435		187.0		1290		12.6		0		837		3535		7.5		10.0		6307	
56-1-3	20/04/83	415		220.0		1260		12.0		0		620		3600		47.0		8.0		6150	
56-1-4	18/05/83	505		215.0		1240		13.0		0		1002		3960		2.0		8.0		6960	
56-1-5	23/06/83	515		225.0		1300		13.0		0		990		4060		6.0		6.0		7130	
56-1-6	27/07/83	485		220.0		1320		12.0		0		1011		4020		6.2		8.2		7097	
56-1-7	31/08/83	450		220.0		1360		13.0		0		990		3960		3.9		9.4		6881	
56-1-8	30/09/83	460		210.0		1400		13.0		0		1087		3840		7.1		10.0		6999	
56-1-9	28/10/83	465		220.0		1500		16.0		0		1137		4080		4.5		12.0		7450	
56-1-10	29/11/83	255		225.0		1360		14.0		0		434		3900		15.0		8.9		6227	
56-1-11	06/01/84	415		215.0		1240		14.0		0		1031		3600		6.5		7.8		6544	
	Mean	279.5		140.9		1748.7		15.2		0.8		1045		5186		3.7		10.8		7443	
	SD	123.3		89.8		684.6		6.0		2.2		276		1820		3.7		8.4		2644	
	N	24		24		24		24		24		24		24		24		24		24	

[a] Symbol: Bracket indicates mean of multiple sampling of one well; $\bar{X}$ = mean; SD = standard deviation; N = number of samples taken: 0 = value of zero.

Table 5. Summary of major ionic constituents in spoil groundwater, Vesta Mine. (Concentrations in mg/L).

	Mean	SD[a]	Range	Common Range
TDS[a]	7035	2434	3057 to 13805	4500 to 9000
Na	1678	670	872 to 3070	1100 to 2000
Ca	264	143	13 to 460	300 to 400
Mg	130	87	2.9 to 279	100 to 250
SO_4	3909	1713	1344 to 8400	2500 to 5000
HCO_3	1019	292	627 to 1690	700 to 1200

[a] Symbols: SD = standard deviation; TDS = total dissolved solids.

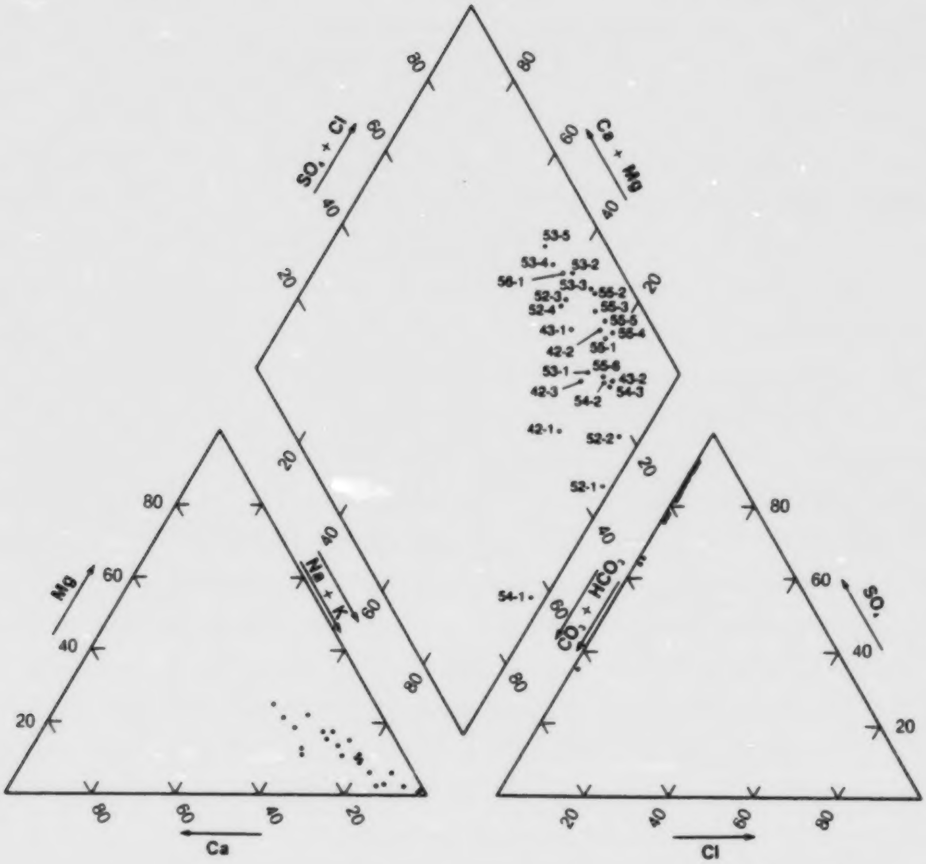


Figure 6. Piper trilinear diagram of spoil groundwater composition, Vesta Mine.

anion of significance in the spoil groundwater at Vesta Mine; concentrations of chloride and nitrate are negligible. From 5 to 25% of the anionic fraction of the spoil groundwater is bicarbonate as shown in Figure 6.

3.3 HIGHVALE MINE

Groundwater in the spoil at Highvale Mine is characterized by moderate to high TDS concentrations, sodium as the dominant cation, and bicarbonate and sulfate as the dominant anions. Table 6 is a listing of the major ion analyses of groundwater from the spoil at Pit 01 of the Highvale Mine, Table 7 summarizes these data, and Figure 7 is a Piper trilinear diagram of the spoil groundwater composition.

The spoil groundwater at Pit 01 of Highvale Mine is 2.4 times more saline than the premining groundwater from the sandstone overburden of the Paskapoo Formation. Increases in the concentrations of various constituents are all of the same order, ranging from an increase of 2.3 times for Na^+ to 8.1 times for SO_4^{2+}. This subject is discussed in more detail in Section 4.

Sodium is the dominant cation in most samples of groundwater from the spoil at Highvale Mine, making up over 85% of the cation component in more than two-thirds of the samples (Figure 7). Potassium, which is included with sodium in terms of the Piper trilinear diagram is present in very small amounts only, in all cases less than 20 mg/L, and generally below 12 mg/L. Calcium makes up from 2 to 60% of the cation composition of spoil groundwater from Highvale Mine, although calcium exceeds 30% of the cations in only 15% of the samples (Figure 7). Magnesium is typically less than 10% of the cations, although in 18% of the samples, magnesium makes up from 15 to 30% of the cation composition.

Bicarbonate and sulfate are equally important anionic species in the spoil groundwater at Highvale Mine, each forming the dominant anion in about half the samples. Bicarbonate concentrations in the Highvale spoil groundwater are substantially less variable

Table 6. Highvale Mine spoil - major ion chemistry (all values in mg/L).

Sample ID	Date	Ca^{2+}	$\bar{X}$	Mg^{2+}	$\bar{X}$	Na^{+}	$\bar{X}$	K^{+}	$\bar{X}$	CO$_3^{2-}$	$\bar{X}$	HCO$_3^{-}$	$\bar{X}$	SO$_4^{2-}$	$\bar{X}$	NO$_3^{-}$	$\bar{X}$	Cl^{-}	$\bar{X}$	TDS	$\bar{X}$
2-1-1	21/10/82	28.4		4.0		919		3.3		0		1476		775		2.8		3.0		3737	
2-2-1	21/10/82	6.9		3.0		1100		2.1		0		2754		62		52.0		38.0		4044	
3-1-1	05/11/82	11.7		3.0		1100		2.1		0		1553		117		1.0		14.0		2422	
3-2-1	11.05/82	71.0		61.0		1040		8.9		0		2613		522		2.0		36.0		4388	
3-3-1	12/05/82	284.0		101.0		1320		13.0		0		1409		2625		4.5		14.0		5904	
6-1-1	29/09/82	207.0		29.8		1719		15.8		0		1689		3143		15.6		14.0		6855	
6-2-1	29/09/82	40.3		11.9		1529		7.7		0		1513		1926		13.3		4.0		5058	
6-3-1	30/09/82	125.0	134.0^{a}	17.8	20.0	1362	1390	12.9	12.0	0	5.3	1393	1372	2013	2164	2.0	6.9	4.0	3.7	4948	5073
6-3-2	28/04/83	159.0		20.0		1387		11.0		0		1480		2130		0.28		2.0		5202	
6-3-3	26/05/83	175.0		22.0		1320		12.0		0		1399		2235		1.7		0.0		5196	
6-3-4	28/07/83	163.0		21.0		1360		11.0		0		1439		2145		26.0		4.5		5183	
6-3-5	26/08/83	114.0		20.0		1440		12.0		0		1393		2175		15.0		5.4		5189	
6-3-6	05/10/83	137.0		19.0		1400		11.0		0		1522		2175		3.0		4.4		5147	
6-3-7	03/11/83	174.0		21.0		1480		11.0		0		1457		2235		1.6		4.7		5398	
6-3-8	30/11/83	8.7		19.0		1420		14.0		48		844		2235		6.1		3.7		4301	
6-3-9	12/01/84	149.0		20.0		1340		13.0		0		1425		2130		6.7		4.5		5101	
7-1-1	22/10/82	24.9	36.3	5.0	5.8	725	715	3.2	3.4	0	0	1625	1478	148	107	1.6	53.1	31.0	33.0	2589	2642
7-1-2	29/04/83	41.0		6.5		750		4.0		0		1747		138		3.4		36.0		2746	
7-1-3	30/06/83	42.0		6.0		715		3.7		0		1691		108		40.0		31.0		2660	
7-1-4	02/09/83	31.0		5.2		700		2.8		0		1820		90		3.7		32.0		2553	
7-1-5	03/11/83	41.0		6.0		735		2.7		0		1774		86		0.8		34.0		2704	
7-1-6	12/01/84	38.0		5.9		665		3.9		0		1749		72		3.6		36.0		2598	
7-2-1	22/10/82	124.0		17.2		1044		9.7		0		1537		1415		4.3		5.0		4170	
7-3-1	11/05/83	205.0		28.0		760		19.0		0		775		1335		1.2		4.0		3143	
8-2-1	23/11/82	20.6		2.6		775		2.6		0		1321		639		1.3		12.0		2818	
8-3-1	24/11/82	101.0		22.8		34		1.3		0		1693		15		12.5		2.0		1881	
8-4-1	24/11/82	166.0	156.0	38.6	38.0	142	129	4.3	4.5	0	0	824	686	121	75	3.9	6.6	3.0	10.2	1328	1273
8-4-2	29/04/83	168.0		39.0		144		4.5		0		884		105		0.64		4.0		1373	
8-4-3	30/06/83	163.0		40.0		127		4.8		0		817		77		25.0		3.0		1280	
8-4-4	26/08/83	138.0		35.0		118		4.4		0		753		57		0.8		2.4		1196	
8-4-5	03/11/83	154.0		37.0		120		4.0		0		839		48		6.0		48.0		1242	

continued . . .

Table 6. Concluded.

Sample ID	Date	Ca^{2+}	$\bar{X}$	Mg^{2+}	$\bar{X}$	Na^{+}	$\bar{X}$	K^{+}	$\bar{X}$	CO_3^{2-}	$\bar{X}$	HCO_3^{-}	$\bar{X}$	SO_4^{2-}	$\bar{X}$	NO_3^{-}	$\bar{X}$	Cl^{-}	$\bar{X}$	TDS	$\bar{X}$
8-4-6	12/01/84	145.0		36.0		120		5.0		0		842		43		3.2		2.5		1219	
9-1-1	08/10/82	12.7		0.0		1388		5.2		317		0		1840		3.5		41.0		4120	
9-2-1	21/10/82	19.0	69	19.3	19.0	1004	866	10.1	6.8	9	3.7	1201	1329	1158	1026	9.6	11.0	10.0	6.3	3455	3303
9-2-2	04/05/83	54.0		22.5		937		10.2		0		1362		1349		11.0		8.0		3776	
9-2-3	26/05/83	95.0		22.0		845		11.0		0		1492		1140		5.8		2.0		3576	
9-2-4	28/07/83	116.0		21.0		835		10.0		0		1254		960		30.0		6.2		3258	
9-2-5	02/09/83	29.0		17.0		830		9.6		0		1430		915		5.8		6.2		2911	
9-2-6	05/10/83	62.0		16.0		775		6.9		0		1393		825		2.3		5.3		3108	
9-2-7	03/11/83	105.0		17.0		835		10.0		17		1171		840		10.0		6.2		3035	
10-1-1	19/10/82	37.6		7.8		1100		5.8		0		1693		1109		3.8		10.0		3981	
10-2-1	19/10/82	47.0	73	13.2	14.0	1206	1202	5.5	5.8	0	0.0	1613	1722	1507	1346	4.6	2.3	5.0	7.1	4420	4382
10-2-2	28/04/83	44.0		12.0		1156		4.9		0		1792		1320		0.82		6.0		4352	
10-2-3	30/06/83	112.0		14.0		1270		5.6		0		1800		1350		3.3		7.2		4580	
10-2-4	26/08/83	57.0		14.0		1200		6.1		0		1578		1320		1.0		8.0		4168	
10-2-5	04/11/83	122.0		15.0		1260		5.4		0		1786		1350		2.3		8.0		4567	
10-2-6	12/01/84	54.0		14.0		1120		7.4		0		1764		1230		1.6		8.6		4202	
10-3-1	20/10/82	315.0		47.6		881		11.3		0		1369		1676		7.2		5.0		4336	
11-1-1	01/10/82	34.0		9.5		838		2.9		0		1761		417		7.8		8.0		3098	
11-2-1	07/10/82	200.0		63.0		95		0.6		0		1075		29		10.3		7.0		1457	
11-3-1	07/10/82	112.0		49.0		361		4.2		0		1289		117		10.8		3.0		1970	
12-1-1	08/10/82	6.0	22	3.8	3.7	838	812	3.4	3.2	2	6.9	1873	1839	220	215	2.9	11.0	6.0	5.2	2989	2911
12-1-2	04/05/83	25.0		3.1		856		2.4		0		1860		225		6.1		4.0		3000	
12-1-3	30/06/83	27.0		3.5		780		2.8		0		1643		213		37.0		5.3		2728	
12-1-4	02/09/83	16.0		3.2		805		2.4		0		1993		213		7.2		4.6		2901	
12-1-5	04/11/83	28.0		3.7		840		2.6		26		1803		213		1.1		5.5		2950	
12-1-6	12/01/84	29.0		4.6		755		5.4		0		1859		207		13.0		5.9		2900	
12-4-1	11/05/83	163.0		15.0		1875		12.0		0		1486		3120		0.9		4.0		6684	
14-1-1	09/12/82	10.2		1.8		685		2.9		0		1473		124		0.9		0.0		2315	
14-2-1	09/12/82	371.0		114.0		600		10.5		0		880		1969		19.4		12.0		3997	
Mean		109.0		26.6		933.7		11.2		12.8		1451		1073		10.2		11.6		3668	
SD		102.0		30.1		464.6		15.4		62.15		540		988		13.4		11.7		1461	
N		27		27		27		27		27		27		27		27		27		27	

[a]Symbol: Bracket indicates mean of multiple sampling of one well; $\bar{X}$ = mean; SD = standard deviation; N = number of samples taken; 0 = value of zero.

Table 7. Summary of major ionic constituents in spoil groundwater, Highvale Mine (Pit 01). (Concentrations in mg/L).

	Mean	SD[a]	Range	Typical Range
TDS[a]	3668	1461	1273 to 6855	2500 to 4500
Na	934	465	95 to 1719	700 to 1400
Ca	109	102	7 to 371	N/A
Mg	26.6	30	0 to 114	N/A
SO_4	1073	988	15 to 3143	N/A
HCO_3	1451	540	753 to 2754	1000 to 2000

[a] Symbols: SD = standard deviation; TDS = total dissolved solids; N/A = non applicable.

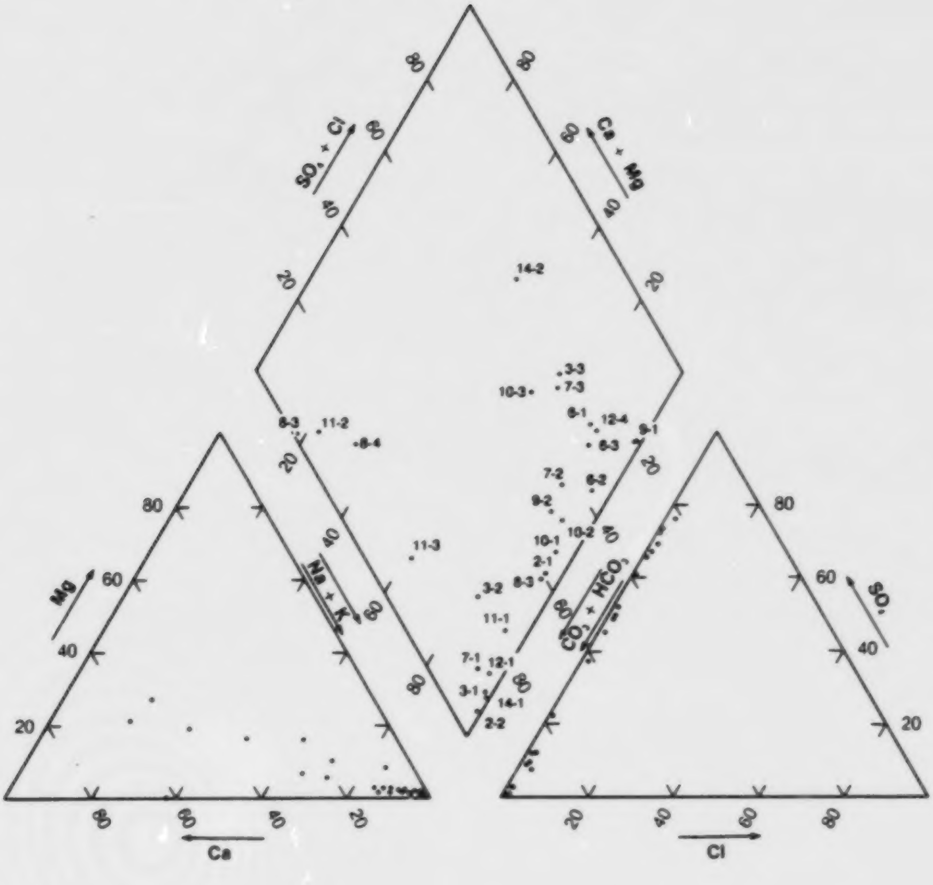


Figure 7. Piper trilinear diagram of spoil groundwater composition, Highvale Mine.

than those of sulfate. Chloride is present only in very small concentrations in the spoil groundwater at Highvale Mine. Chloride concentrations are in all cases less than 50 mg/L, and generally less than 15 mg/L. Among the anionic composition of the spoil groundwater, chloride comprises from 0 to 5%.

3.4 WHITEWOOD MINE

The spoil groundwater at Whitewood Mine is characterized by low to moderate salinity, with calcium as the dominant cation and bicarbonate as the dominant anion. Table 8 is a listing of the major ion analyses of spoil groundwater from Whitewood Mine, Table 9 summarizes these data, and Figure 8 is a Piper trilinear diagram of the spoil groundwater composition. Also included in Table 8 is a summary of water chemistry data from the 1977-78 samplings by Alberta Environment (1980) of piezometers completed in spoil at Whitewood Mine. In most cases, the differences in groundwater chemistry between the earlier Alberta Environment sampling and the 1982 Research Council sampling of the same wells were negligible. Also, overall mean and standard deviation values for seven major ionic constituents, as listed in Table 8, were in reasonably good agreement between the two sets of water chemistry data. Differences in mean concentrations of individual constituents between the two studies ranged from as low as 10% for potassium to 25.7% for calcium. For five of the seven constituents, there was less than 20% difference between the two sets of samples. Consequently, both the Alberta Environment (1980) and Research Council samples have been used to characterize the spoil groundwater chemistry at Whitewood Mine.

The spoil groundwater at Whitewood Mine is 5.9 times more saline than groundwater from the overburden sand and gravel. Sulfate concentrations in the spoil groundwater are 35.6 times higher than in the premining groundwater, and increases in Ca^{2+}, Mg^{2+}, and Na^{+} range from 3.3 times (Mg^{2+}) to 7.5 times (Na^{+}). More detail on this topic is presented in Section 4.

Table 8. Major ion chemistry - Whitewood spoil groundwater (all values in mg/L).

Sample ID	Date	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	SO_4^{2-}	HCO_3^-	NO_3^-	Cl^-	TDS[a]
WW-2A-1	10/11/82	167	36	90.0	4.8	136	702	2.8	0	1159
WW-4-1-1	09/11/82	255	68	33.8	12.0	379	684	5.0	0	1459
WW-4A-1	09/11/82	232	55	78.0	5.3	321	684	10.6	0	1408
WW-4B-1	09/11/82	234	84	56.0	6.0	30	1504	4.8	6	1936
WW-4C-1	12/11/82	295	92	67.0	3.1	353	984	44.0	3	1859
WW-5C-1	16/11/82	196	46	45.0	4.7	190	640	74.0	2	1220
WW-6A-1	17/11/82	206	43	7.6	6.3	200	620	3.3	0	1097
WW-6C-1	02/12/82	182	42	12.0	2.8	95	572	1.1	0	938
WW-7B-1	03/11/82	275	86	100.0	5.9	148	1217	12.0	4	1869
WW-7C-1	17/12/82	210	52	21.0	5.5	24	873	7.6	5	1218
WW82-314-3-1	03/12/82	190	41	64.0	9.4	87	768	2.6	2	1186
Mean		222	58.6	52.2	6.0	178	841	15.2	2	1395
Standard Deviation		38.4	19.4	29.7	2.5	119	276	21.8	2.1	330
Mean	Alta Env, 1980	165	48	61	6.6	139	748	ND[a]	3	1171
Standard Deviation		47	18	68	2.5	77	291	ND	2	380
Overburden Sand and Gravel										
Mean		65	17.9	7.0	3.8	5.0	310	0.18	2.5	236
Standard Deviation		19	8.2	5.0	2.2	3.5	83	0.26	1.3	40

[a] Symbol: TDS = total dissolved solids; 0 = value of zero; ND = not determined.

Table 9. Summary of major ionic constituents of spoil groundwater, Whitewood Mine. (Concentrations in mg/L).

mg/L	Mean	SD[a]	Range	Common Range
TDS[a]	1395	330	938 to 1856	NA[a]
Na	52	30	8 to 100	20 to 80
Ca	222	38	167 to 295	NA
Mg	59	19	36 to 92	NA
K	6	2.5	3 to 12	NA
SO_4	178	119	24 to 378	NA
HCO_3	841	276	572 to 1509	600 to 1000

[a] Symbols: NA = not applicable; TDS = total dissolved solids; SD = standard deviation.

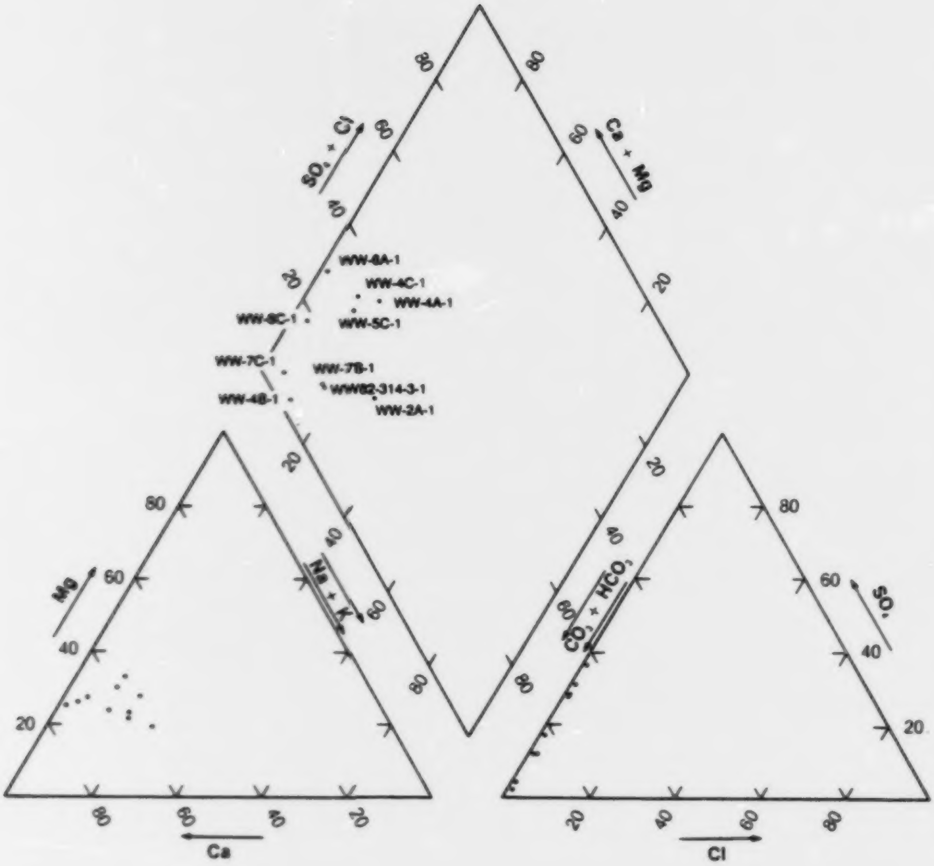


Figure 8. Piper trilinear diagram of spoil groundwater composition, Whitewood Mine. Research Council samples only.

The TDS concentrations in spoil groundwater at Whitewood Mine are within the narrow range of from 713 to 1936 mg/L. This narrow range of salinity is reflected in the relatively uniform composition of the spoil groundwater, as shown in Tables 8 and 9 and Figure 8. In general, the spoil groundwater at Whitewood Mine is of Ca^{2+}, Mg^{2+} - HCO_3^- composition, with sulfate making up from 2 to 40% of the anionic component.

Calcium, which is the dominant cation in the spoil groundwater at Whitewood Mine, ranges in concentration from 125 to 295 mg/L. Magnesium is the second most abundant cation in the spoil groundwater at Whitewood Mine, with concentrations ranging from 23 to 92 mg/L (Table 8). The dominance of Ca^{2+} and Mg^{2+} in the spoil groundwater is probably a reflection of the calcareous nature of the glacial sediment that makes up much of the overburden at Whitewood Mine.

Sodium concentrations in the spoil groundwater are quite variable, although generally less than 100 mg/L. Therefore sodium is only a minor component of the spoil groundwater ranging from 3 to 30% of the cation fraction in most cases. Potassium is the least abundant major cation in the spoil groundwater at Whitewood Mine, with concentrations less than 13 mg/L (Table 8). As previously mentioned, bicarbonate, which is the dominant anion in the spoil groundwater at Whitewood Mine (Table 8, Figure 8), ranges from 60 to 98% of the anion fraction. Sulfate, which is the second most important anionic constituent in the spoil groundwater at Whitewood Mine, is in all cases less than 40% of the anionic fraction. Sulfate concentrations are quite variable, as suggested by the relatively large standard deviation (Tables 8 and 9). Chloride, with a mean concentration of 2.0 mg/L is a negligible component of the spoil groundwater composition. Nitrate, on the other hand, with a mean concentration of 15.2 mg/L, approached or exceeded the recommended maximum concentration of 45 mg/L (McNeely et al. 1979) in two of 11 wells, WW-4C and WW-5C (Table 8).

3.5 DISCUSSION

The relative proportion of the major ions in groundwater from spoil at Diplomat and Vesta Mines at the Battle River mining area is similar, although the abundance of the various ions is different (Table 1; Figures 2 to 6). Water in Vesta spoil is appreciably more saline (Figure 4) with only magnesium, potassium, and chloride not significantly different at the 95% level (Figure 2). The water in spoil at Highvale and Whitewood Mines in the Lake Wabamun mining area is significantly less saline than that at Battle River (Table 1; Figure 4). The ionic makeup of the water is also significantly different (Table 1; Figures 2, 3, 5 to 8). Highvale and Whitewood Mines are also significantly different from one another in total salinity and in most components (Table 1; Figures 2 to 4, 7 to 8).

The differences in groundwater chemistry can be related to similar differences in mineralogical and chemical properties in the overburden at the various mines sites (Maslowski Schutze 1986, in press). The largest observed difference in overburden characteristics is between glacial till on the one hand and bedrock of the Horseshoe Canyon Formation (Battle River) and Paskapoo Formation (Lake Wabamun) on the other. It is, therefore, not surprising that the groundwater chemistry in spoil at Diplomat Mine, which is almost entirely derived from till, differs from that at Vesta Mine, where the spoil is largely derived from bedrock of the Horseshoe Canyon Formation. Similarly, the spoil at Whitewood Mine is derived largely from unconsolidated drift and nonclayey bedrock, whereas the spoil at Highvale Mine is derived largely from clayey bedrock of the Paskapoo Formation.

Explanation of the differences in chemistry of groundwater in spoil between the Battle River and Lake Wabamun mining areas is not as straightforward. The degree to which these chemical differences can be ascribed to geological causes as opposed to climatic and hydrological causes is not at all clear. The bedrock overburden at the Battle River site, the Lower Horseshoe Canyon Coal

Zone, was deposited in a marine-margin environment (Maslowski Schutze et al. 1986). The bedrock overburden at the Lake Wabamun mining area, on the other hand, is part of the Ardley Coal Zone, which was deposited in a fluvial plain environment (Maslowski Schutze in press). In other areas of North America it has been demonstrated that this type of difference in deposition environment produces differences in the mineralogy of the sediment (Maslowski Schutze et al. 1986, p. 32). The major mineralogical difference observed between these two study areas is that smectite makes up a considerably greater proportion of the clay minerals in bedrock sediment in the Battle River mining area (81% on average) than in the Lake Wabamun mining area (64% on average). Cation exchange data and chemistry of saturation paste extracts further indicate a considerably higher amount of sodium available in bedrock overburden at Battle River than at Lake Wabamun (Maslowski Schutze 1986, in press).

It is not known whether the mineralogical and chemical difference between the two study sites is solely a reflection of geological differences or whether it is partly a response to the different climate in the two areas. The Battle River site is located in a warmer and drier climatic zone than is the Lake Wabamun site. Precipitation is less and potential evapotranspiration is greater at the Battle River site. It is thus possible that the greater abundance of sodium at the Battle River site reflects less flushing and leaching and greater retention of monovalent cations in the shallow overburden than at Lake Wabamun.

With existing data it is not possible to evaluate the relative importance of these two mechanisms, one geologic and the other climatic, in determining the differences in spoil groundwater chemistry between the two study areas. Thus it is not clear whether spoil at a mine site in the Ardley Coal Zone east of Red Deer would produce groundwater chemistry similar to Battle River (climatic dominance) or Lake Wabamun (geological dominance). Similarly, it is not known whether a mine near Barrhead in sediment equivalent to the

Lower Horshoe Canyon would result in spoil groundwater chemistry similar to Battle River (geological dominance) or Lake Wabamun (climatic control).

4. CHANGES IN MAJOR ION CHEMISTRY OF GROUNDWATER: SPOIL VERSUS UNMINED

In all four of the mines studied there is a significant increase in groundwater salinity as a result of mining, ranging from 2.4 times to 5.9 times the premining level (Table 10, Figure 9). Highvale Mine spoil shows the smallest increase in groundwater salinity, at 2.4 times the premining concentration. Diplomat and Vesta Mines show moderate increases in salinity, at 2.9 and 3.0 times the premining level, respectively. Whitewood Mine, which has the lowest salinity spoil groundwater (1395 mg/L), curiously shows the greatest increase relative to the premining level, at 5.9 times. This is largely a reflection of the very low TDS concentration of the premining groundwater, 236 mg/L (Montreal Engineering 1979). The average TDS increase (spoil/premining) observed at these four sites is 3.8 times.

Of individual constituents, sulfate shows the greatest increase in the spoil groundwater relative to the premining groundwater (Table 10). The increase in sulfate concentrations range from 8.1 times the premining level at Highvale Mine to 124 times at Vesta Mine, with the average increase of the four mines at 60 times (Table 10). At three of the four mines (Whitewood Mine is the exception) magnesium, then calcium, showed the next largest increase in concentration relative to premining levels (Table 10).

In terms of compositional changes, the spoil groundwater at Vesta and Diplomat Mines represents the greatest shift from premining groundwater composition. Only the bicarbonate content does not show a significant increase at the 95% level. The observed change from the premining $Na^+ - HCO_3^-, Cl^-$ to (Na^+, Ca^{2+}) or $(Ca^{2+}, Na^+) - SO_4^{2-}$ composition appears to be related to the presence of high salinity, high sulfate zones in the drift, and weathered bedrock in the Battle River mining area (Trudell et al. 1983). At Highvale Mine, there is an intermediate magnitude of change in spoil groundwater composition, with most samples showing an increase in the sulfate component of the anionic composition, but with several samples retaining the

Table 10. Summary of spoil groundwater chemical characteristics - central Alberta.

Mine	Coal Zone	Nature of Overburden	Spoil Groundwater Chemistry								Δ Premining				
			TDS	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	SO_4^{2-}	HCO_3^{-}	Cl^{-}	Ca^{2+}	Mg^{2+}	Na^{+}	SO_4^{2-}	TDS
			$\overline{X}$[a] σ	$\overline{X}$ σ	$\overline{X}$ σ	$\overline{X}$ σ	$\overline{X}$ σ	$\overline{X}$ σ	$\overline{X}$ σ	$\overline{X}$ σ					
Whitewood	Ardley	Sand and Gravel	1395	222	58.6	52.2	6.0	178	841	2.0	3.4	3.3	7.5	35.6	5.9
		and Paskapoo Fm	330	38.4	19.4	29.7	2.5	119	276	2.1	WW				
Highvale	Ardley	Paskapoo Fm	3668	109	26.6	934	11.2	1073	1451	11.6	4.4	5.4	2.3	8.1	2.4
		and Glacial Till	1461	102	30.1	465	15.4	988	540	11.7	HV				
Diplomat	Lower Horseshoe	Glacial Till	5708	381	174	1114	14.9	3094	900	11.4	11.0	47.0	1.7	73.8	2.9
	Canyon Fm		1835	88.4	136	493	4.7	1149	259	10.5	D				
Vesta	Lower Horseshoe	Horseshoe Can Fm	7443	280	141	1749	15.2	5186	1045	10.8	8.1	38.1	2.7	124	3.9
	Canyon Fm	and Glacial Till	2644	123	89.8	685	6.0	1820	276	8.4	V				

[a] Symbols: $\overline{X}$ = mean; σ = standard deviation; WW = Whitewood Mine; HV = Highvale Mine; D = Diplomat Mine; V = Vesta Mine; TDS = total dissolved.

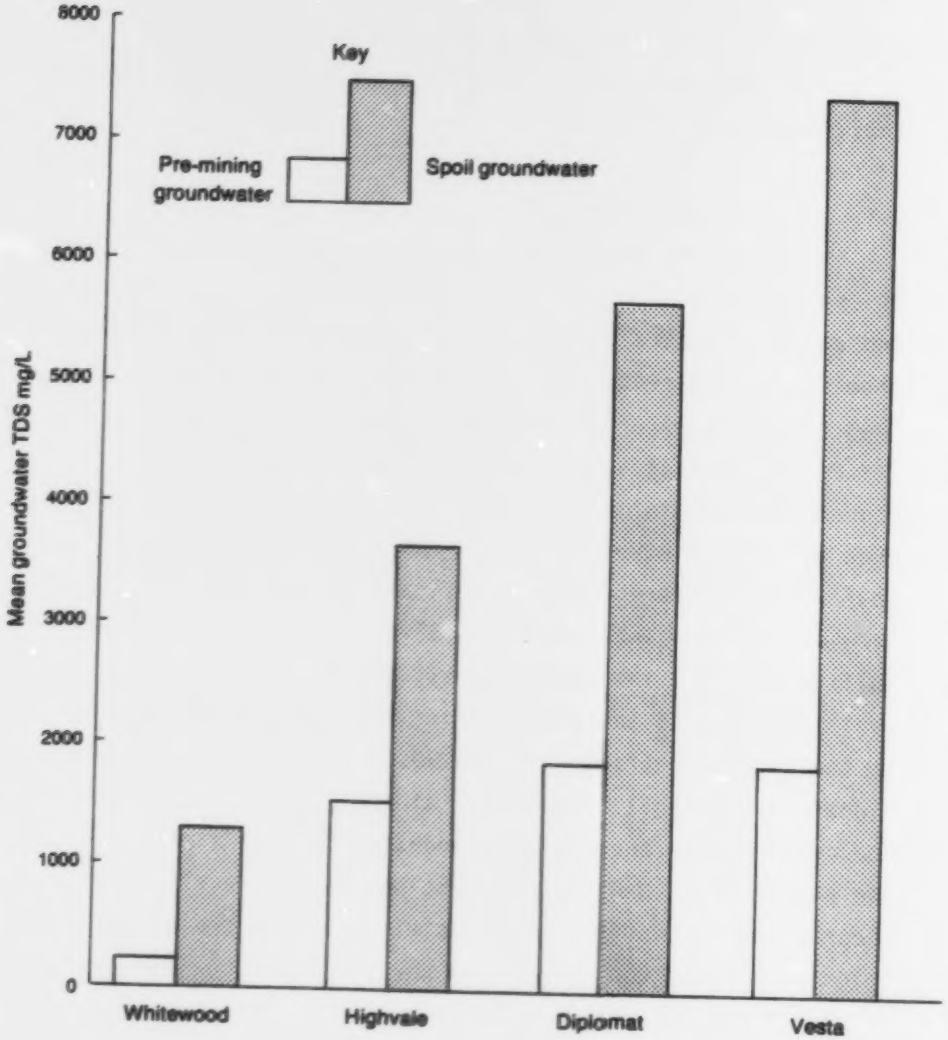


Figure 9. Comparison of spoil groundwater salinity and premining groundwater salinity at the Plains Hydrology and Reclamation Project study mine sites.

$Na^+ - HCO_3^-$ or Ca^{2+}, Mg - HCO_3^- composition of the premining overburden bedrock and drift. Only bicarbonate and chloride do not exhibit increases significant at the 90% level. At Whitewood Mine there is very little change in composition (relative to the unmined overburden) shown by the spoil groundwater, although in several samples the sulfate component increased by 10 to 20%.

The remainder of this section is a detailed discussion of individual mine sites.

4.1 DIPLOMAT MINE

The differences between the chemistry of spoil groundwater at Diplomat Mine and the premining groundwater from the Battle River Bed can be illustrated by pairs of histograms for concentrations of chemical constituents from the two sources (Figures 10 to 17). Chemical analyses of water samples from the Battle River Bed are listed in Table 11. Comparing mean concentrations, the spoil groundwater at Diplomat Mine is approximately 3 times more saline than the Battle River Bed (mean TDS of 5875 mg/L vs 1895 mg/L in the coal). The difference is significant at the 99.5% level. The largest relative increases in individual ions are observed for sulfate (70-fold increase [significant at the 99.5% level] in the spoil relative to the Battle River Bed), magnesium (50 times higher in the spoil significant at the 99.5% level), and calcium (11 times higher in the spoil significant at the 99.5% level). The mean sodium concentration in the spoil groundwater is approximately twice that of the Battle River Bed (significant at the 95% level) whereas mean bicarbonate concentrations are similar in the two units. Chloride, which is a minor constituent in the spoil groundwater, is 24 times higher in the Battle River Bed groundwater than in spoil groundwater (significant at the 99.5% level). Bicarbonate is the only major constituent that is not significantly different at the 95% level.

4.2 VESTA MINE

The difference in water quality between the spoil groundwater at Vesta Mine and the premining groundwater from the

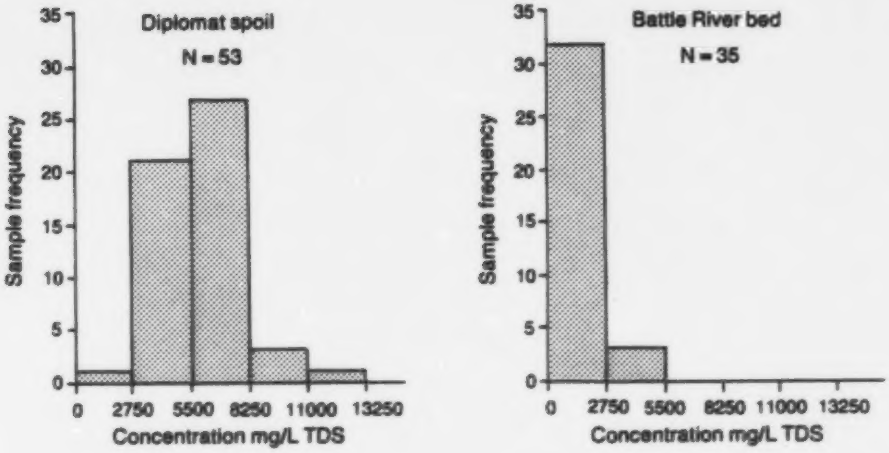


Figure 10. Histogram of total dissolved solids concentration for Diplomat spoil and the Battle River Bed.

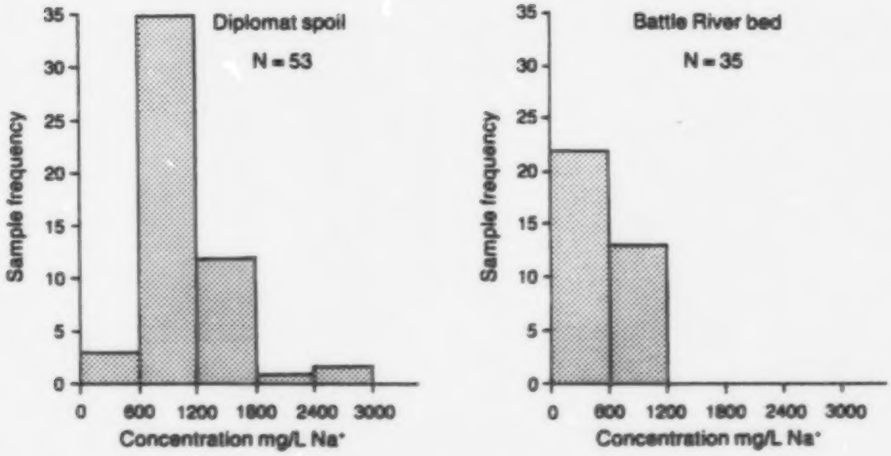


Figure 11. Histogram of Na^+ concentration for Diplomat spoil and the Battle River Bed.

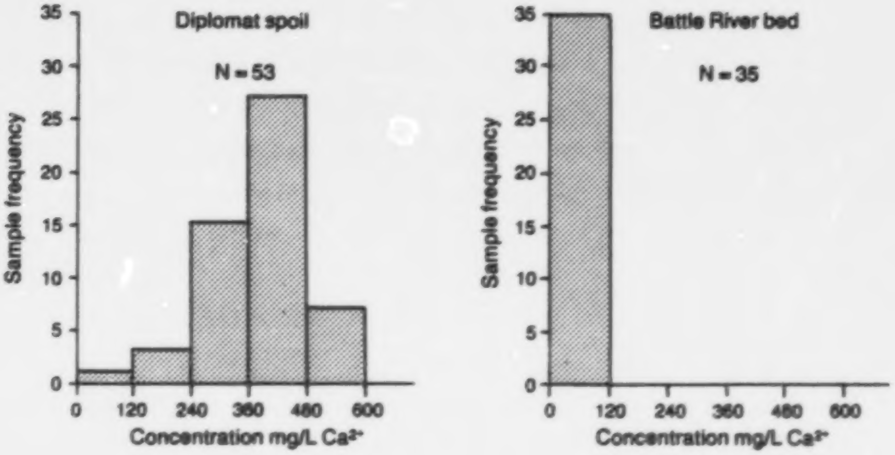


Figure 12. Histogram of Ca^{2+} concentration for Diplomat spoil and the Battle River Bed.

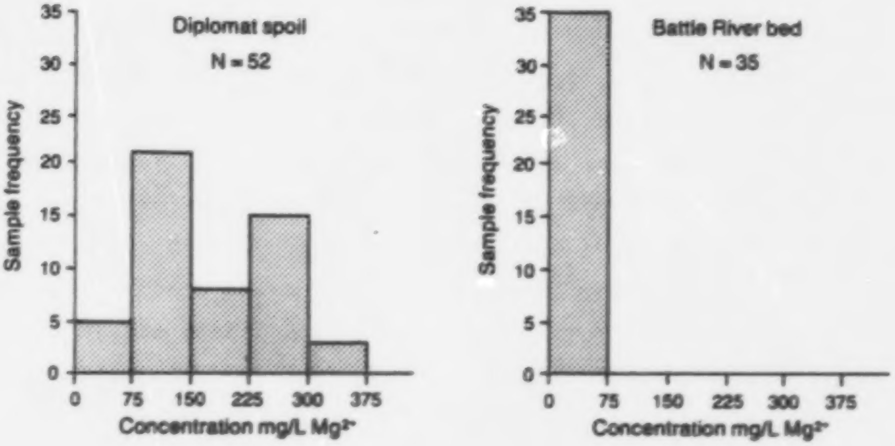


Figure 13. Histogram of Mg^{2+} concentration for Diplomat spoil and the Battle River Bed.

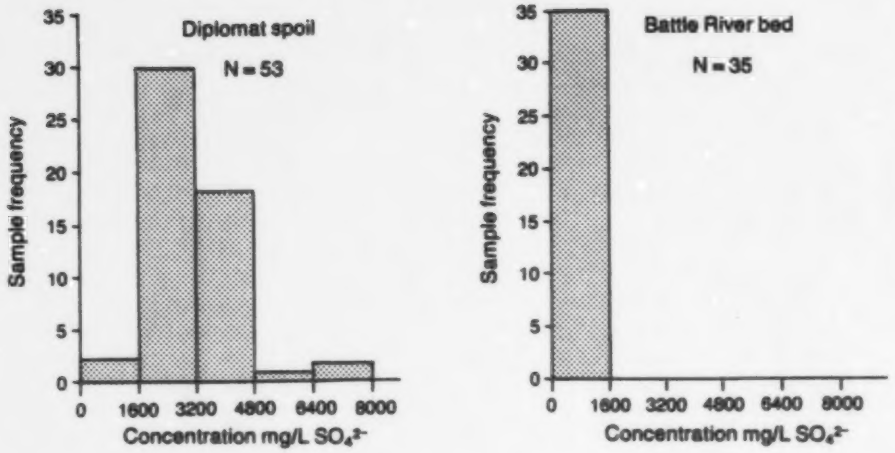


Figure 14. Histogram of SO_4^{2-} concentration for Diplomat spoil and the Battle River Bed.

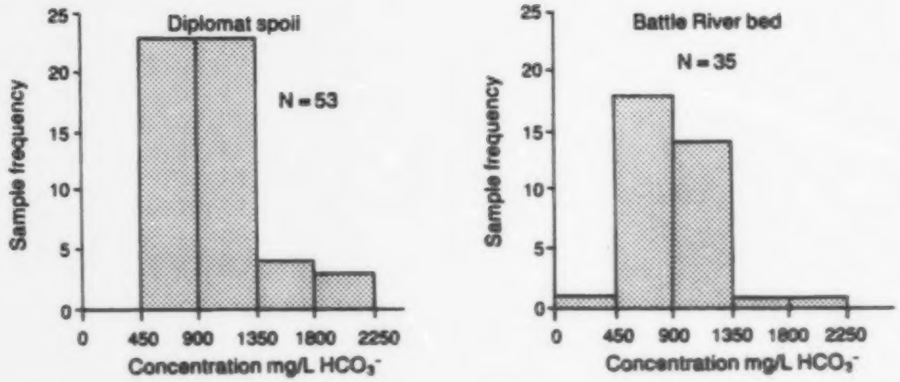


Figure 15. Histogram of HCO_3^- concentration for Diplomat spoil and the Battle River Bed.

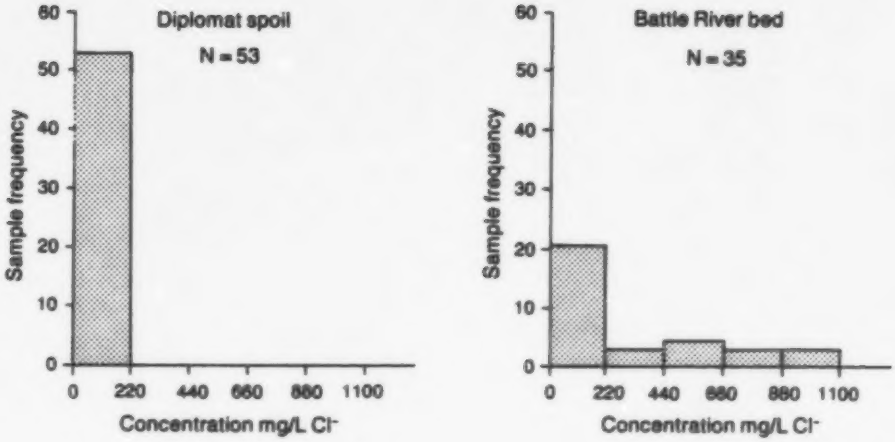


Figure 16. Histogram of Cl^- concentration for Diplomat spoil and the Battle River Bed.

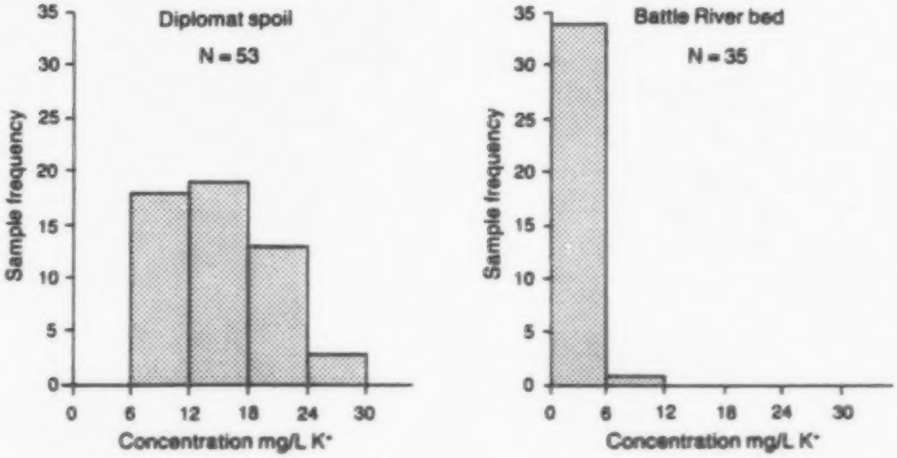


Figure 17. Histogram of K^+ concentration for Diplomat spoil and the Battle River Bed.

Table 11. Battle River Bed - major ion chemistry (all values in mg/L).

Sample ID[a]	Date[c]	Ca^{2+}	Mg^{2+}	Na^+	K^+	CO_3^{2-}	HCO_3^-	SO_4^{2-}	NO_3^-	Cl^-	TDS[b]
1-3-1	06/05/81	10	1.3	609	4.6	15.3	782	31	1.7	533	1789
2-2-1	14/05/81	11	1.5	690	2.9	0.0	597	113	0.7	516	2176
3-2-1	20/05/82	3	1.7	324	1.5	270.0	0	12	1.0	159	898
4-2-1	26/11/80	7	0.9	553	2.3	0.0	2133	212	0.3	21	2037
5-2-1	28/07/81	10	1.4	719	3.3	11.5	1347	21	1.5	285	2424
6-3-1	13/06/80	4	0.8	373	2.9	0.0	952	47	59.0	58	1502
7-2-1	21/04/82	6	0.6	407	1.2	29.0	885	14	20.9	30	1415
8-2-1	10/06/80	11	1.2	713	11.3	0.0	740	11	62.0	576	2131
8-2-2	21/08/80	10	1.1	664	4.9	6.0	783	20	0.0	586	2084
9-4-1	11/06/80	38	0.3	428	1.7	19.8	998	15	3.9	44	1554
9-4-2	27/08/80	5	0.4	413	1.5	8.0	1023	6	0.0	54	1520
12-2-1	13/08/80	13	1.2	583	4.2	35.6	443	129	14.0	560	1790
14-2-1	10/06/80	16	1.5	963	3.8	4.0	728	39	6.5	984	2754
14-2-2	22/08/80	16	2.0	887	3.5	18.0	681	30	0.6	987	2634
15-2-1	19/06/80	9	0.3	494	1.7	13.9	1083	47	1.2	68	1725
15-2-2	30/10/80	6	0.5	452	1.6	0.0	1085	26	0.0	74	1651
16-5-1	21/04/82	3	0.2	292	0.7	6.5	679	8	31.8	14	1047
17-3-1	30/04/81	11	2.6	266	3.8	17.7	483	135	1.0	2	925
23-3-1	07/07/80	8	1.2	465	2.3	23.8	870	29	5.1	142	1557
24-3-1	24/06/82	6	0.7	550	1.7	75.0	990	34	12.2	97	1783
25-3-1	24/06/82	6	1.2	649	1.5	26.4	981	8	1.6	321	2080
26-3-1	13/11/81	17	2.4	894	4.6	43.2	1030	62	0.8	667	2742
27-2-1	10/09/80	14	1.7	769	4.2	13.7	949	83	0.9	623	2472
28-2-1	14/01/80	15	1.7	911	3.4	0.0	1767	21	0.1	775	3507
29-3-1	18/06/80	20	1.8	1063	2.9	0.0	921	44	17.5	1060	3151
45-1-1	15/09/81	8	0.8	440	2.9	399.0	306	39	0.5	92	1301
45-2-1	14/04/82	6	0.6	560	1.6	0.0	1217	8	1.1	123	1899
45-3-1	20/04/82	6	0.8	546	1.7	0.0	1200	5.1	1.1	135	1885
46-2-1	18/06/81	8	1.4	419	5.4	74.6	737	94	2.5	82	1431
47-2-1	23/07/81	9	1.4	594	2.1	0.0	947	29.5	0.2	327	1920
72-1-1	14/12/82	65	1.0	322	2.2	15.4	748	9	1.3	10	1132
73-1-1	17/01/83	8	1.0	226	2.5	6.0	548	13	0.8	5	826
74-1-1	16/12/82	4	1.1	401	1.6	29.9	760	27	3.0	15	1266
75-1-1	17/12/82	45	6.8	643	4.1	0.0	860	953	0.9	2	2515
76-1-1	16/12/82	5	1.3	373	1.9	28.0	844	17	2.1	11	1305
Mean		34.7	3.7	645	3.0	33.3	933	41.9	7.4	287	1895
Standard Deviation		65.4	9.4	343	1.9	79.1	345	44.6	15.0	324	649

[a] Sample ID represents site number - well number - consecutive number sampling.

[b] TDS is calculated total dissolved solids in mg/L.

[c] Date is day/month/year.

Battle River Bed (Table 11) is illustrated by pairs of water quality histograms (Figures 18 to 25). The mean TDS concentration of the spoil groundwater at Vesta Mine (7443 mg/L) is approximately four times that of the Battle River Bed (mean TDS = 1895 mg/L, Table 11). The maximum TDS concentration at Vesta Mine (13 805 mg/L) represents an increase of approximately seven times the mean TDS concentration of the premining groundwater. The individual species showing the greatest increase in spoil groundwater compared to the Battle River Bed are sulfate, magnesium, and calcium. Mean sulfate concentrations in the spoil groundwater are 124 times higher than premining levels, and magnesium and calcium concentrations show an increase of 38 and eight times, respectively, in the spoil groundwater. Chloride, which is a major constituent in the Battle River Bed groundwater, is only a minor component of groundwater from the spoil at Vesta Mine. All these changes are significant at the 95% level.

4.3 HIGHVALE MINE

The spoil groundwater at Highvale Mine has significantly elevated concentrations of all constituents, except chloride, relative to groundwater from the unmined overburden sandstone, as illustrated in comparative histograms (Figures 26 to 33). Chemical analyses of groundwater from the overburden sandstone at Highvale Mine are listed in Table 12. The mean TDS concentration of the spoil groundwater (3668 mg/L) is approximately 2.4 times the overburden groundwater mean TDS of 1549 mg/L. The maximum spoil groundwater salinity, at 6855 mg/L TDS, represents a 4.4 fold increase over the mean premining TDS. Mean concentrations of sulfate, magnesium, and calcium in the spoil groundwater represent the largest increases relative to the unmined overburden groundwater, at levels of 8.1, 5.4, and 4.4 times premining mean concentrations for SO_4^{2-}, Mg^{2+} and Ca^{2+}, respectively.

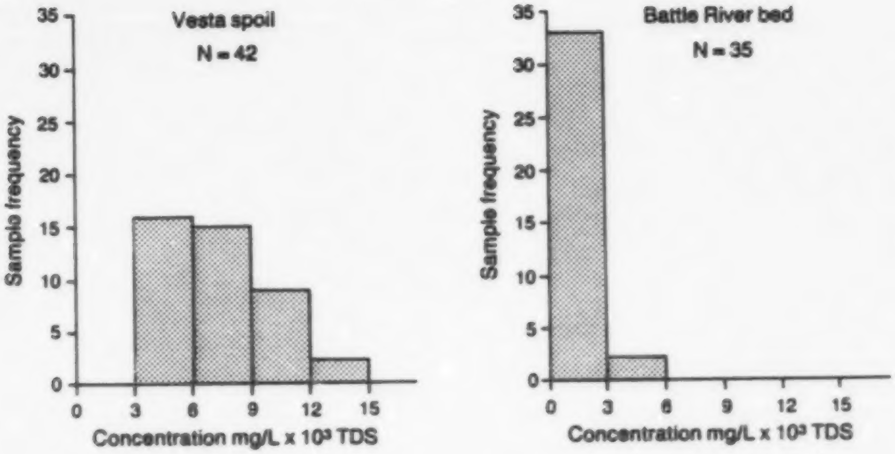


Figure 18. Histogram of total dissolved solids concentration for Vesta spoil and the Battle River Bed.

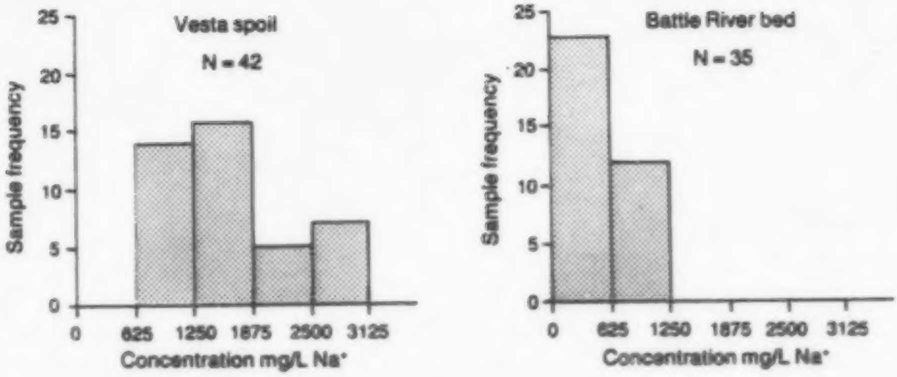


Figure 19. Histogram of Na^+ concentration for Vesta spoil and the Battle River Bed.

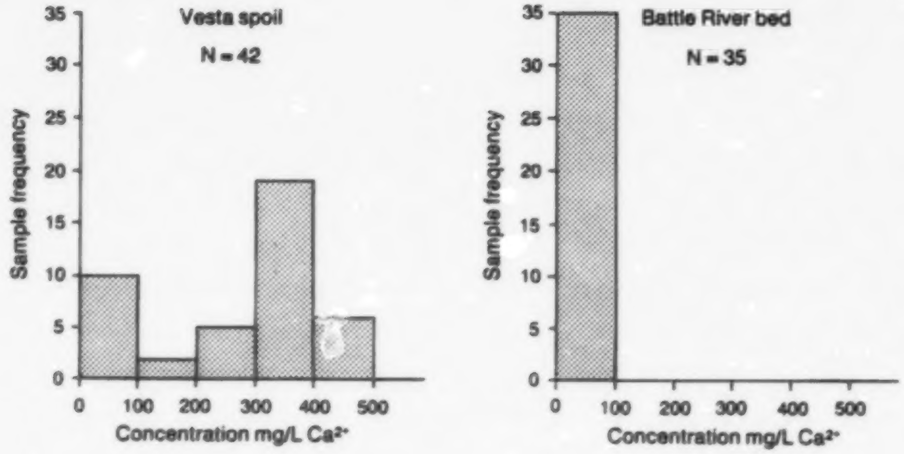


Figure 20. Histogram of Ca^{2+} concentration for Vesta spoil and the Battle River Bed.

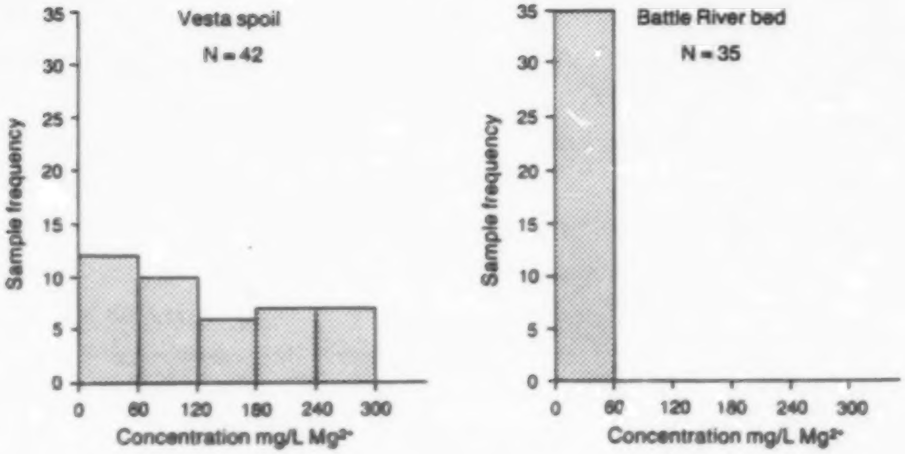


Figure 21. Histogram of Mg^{2+} concentration for Vesta spoil and the Battle River Bed.

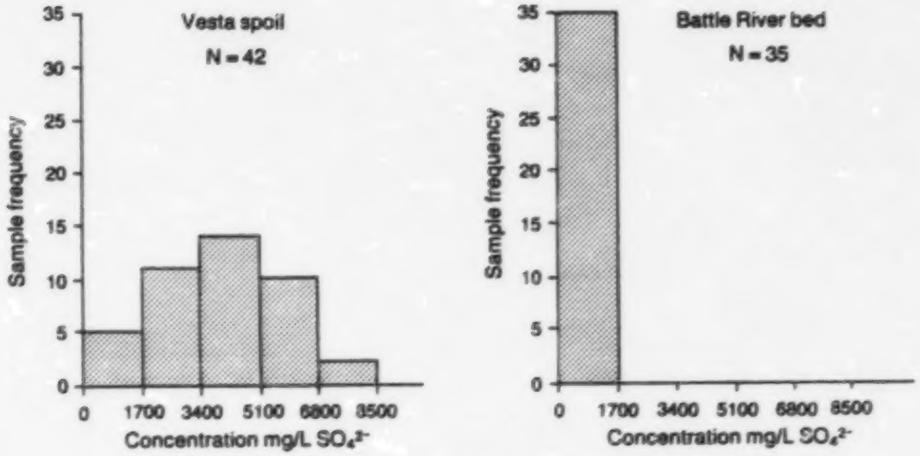


Figure 22. Histogram of SO_4^{2-} concentration for Vesta spoil and the Battle River Bed.

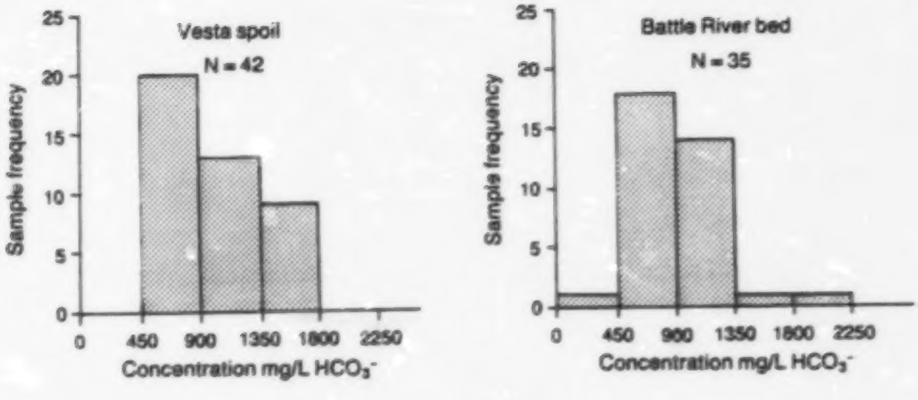


Figure 23. Histogram of HCO_3^- concentration for Vesta spoil and the Battle River Bed.

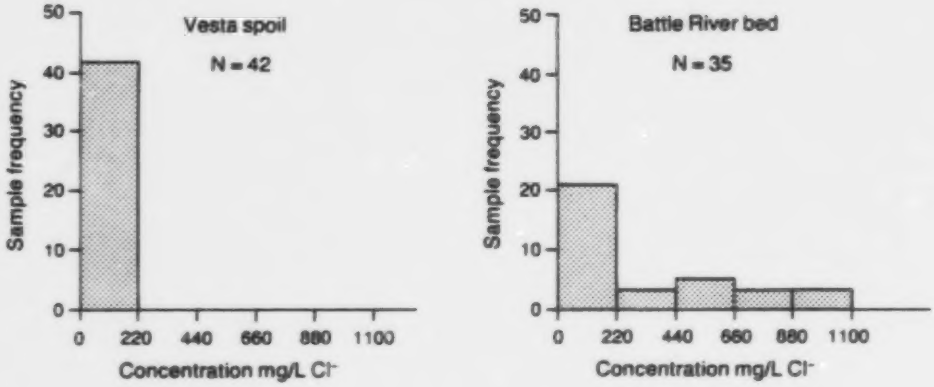


Figure 24. Histogram of Cl^- concentration for Vesta spoil and the Battle River Bed.

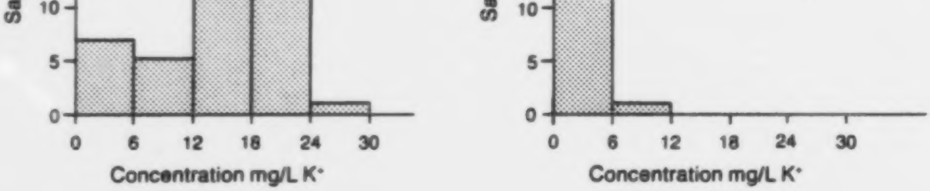


Figure 25. Histogram of K^+ concentration for Vesta spoil and the Battle River Bed.

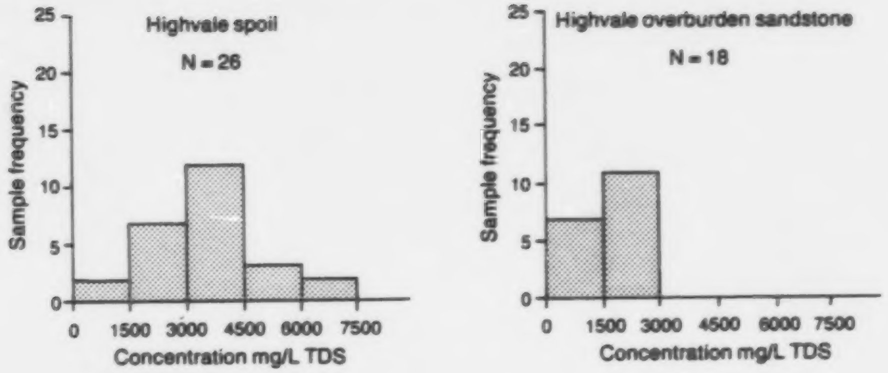


Figure 26. Histogram of total dissolved solids concentration for Highvale spoil and the Highvale overburden sandstone.

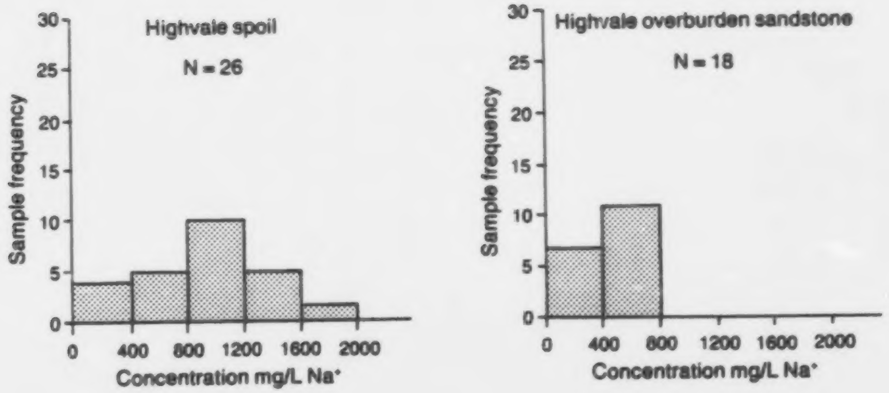


Figure 27. Histogram of Na^+ concentration for Highvale spoil and the Highvale overburden sandstone.

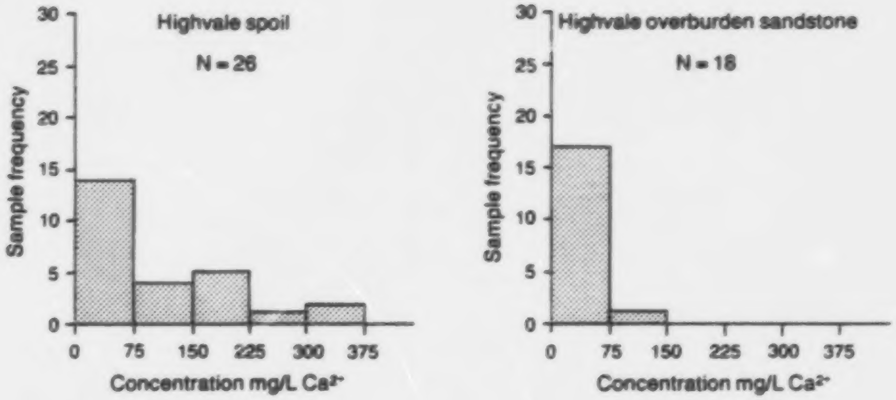


Figure 28. Histogram of Ca^{2+} concentration for Highvale spoil and the Highvale overburden sandstone.

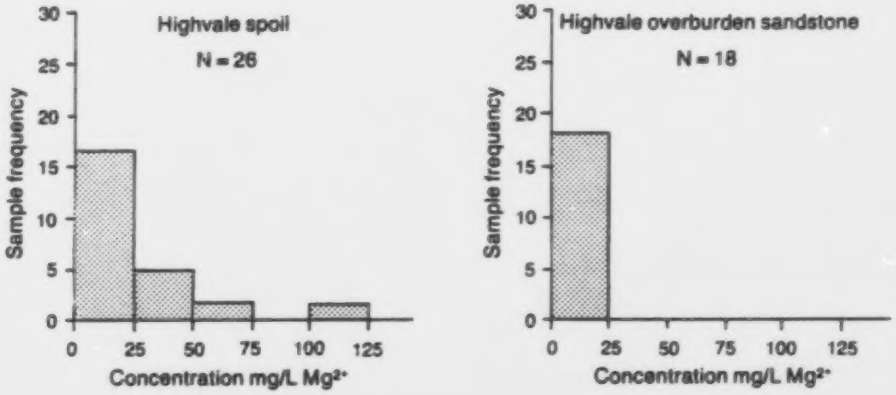


Figure 29. Histogram of Mg^{2+} concentration for Highvale spoil and the Highvale overburden sandstone.

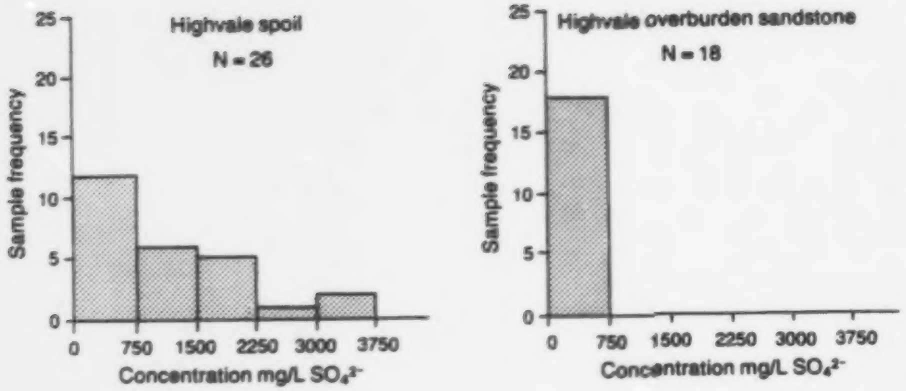


Figure 30. Histogram of SO_4^{2-} concentration for Highvale spoil and the Highvale overburden sandstone.

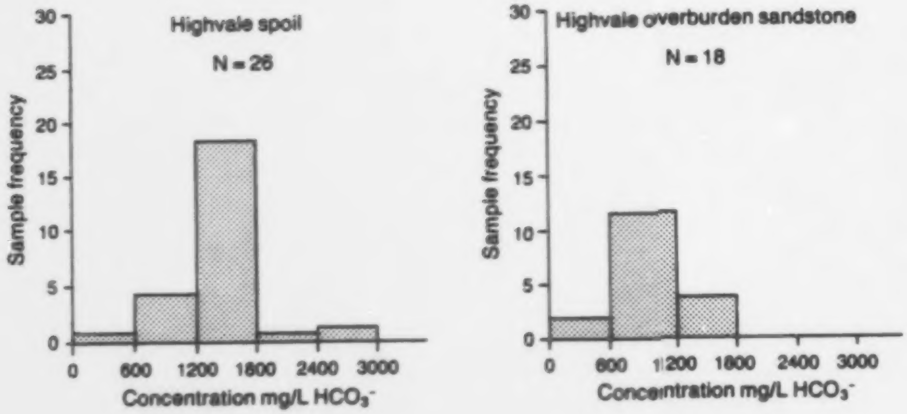


Figure 31. Histogram of HCO_3^- concentration for Highvale spoil and the Highvale overburden sandstone.

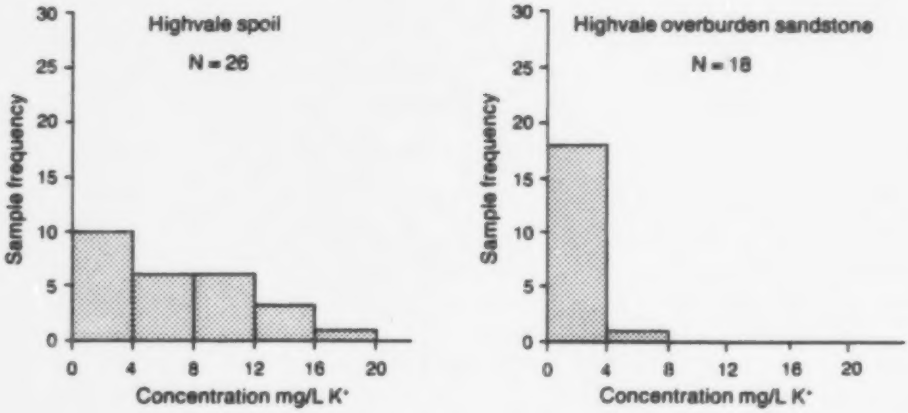


Figure 32. Histogram of K^+ concentration for Highvale spoil and the Highvale overburden sandstone.

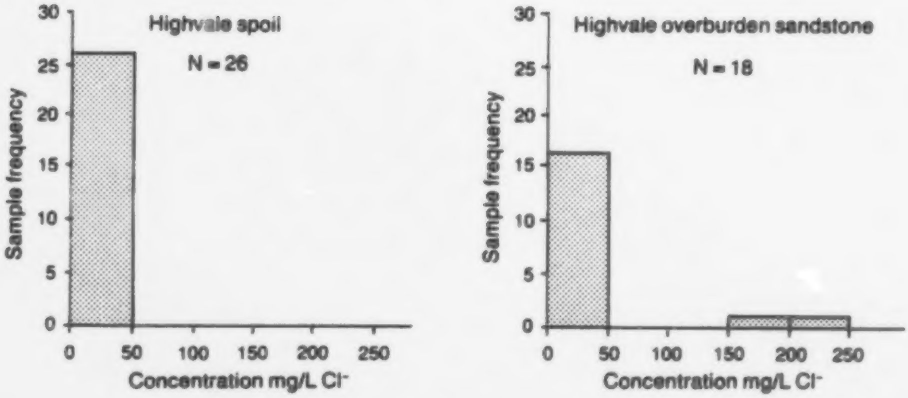


Figure 33. Histogram of Cl^- concentration for Highvale spoil and the Highvale overburden sandstone.

Table 12. Highvale overburden sandstone - major ion chemistry (all values in mg/L).

Sample ID	Date	Ca^{2+}	Mg^{2+}	Na^+	K^+	CO_3^{2-}	HCO_3^{2-}	SO_4^{2-}	NO_3^-	Cl^-	TDS[a]
HV-16-1-1	19/05/83	13.0	1.3	520	2.5	0.0	1353	5.7	6.3	24.0	1936
HV-16-2-1	19/05/83	15.0	1.9	505	2.8	0.0	1326	14.0	6.4	2.0	1884
HV-16-3-1	13/05/83	14.0	1.3	549	2.0	0.0	1523	65.0	1.1	6.0	2217
HV-17-4-1	12/05/83	18.0	1.6	491	2.1	0.0	1035	216.0	0.5	2.0	1776
HV-19-2-1	07/06/83	8.7	1.6	425	2.4	27.5	676	19.0	1.5	212.0	1382
HV-21-1-1	30/09/82	2.3	0.4	425	5.2	47.2	756	297.0	4.4	2.0	1116
HV-22-1-1	03/06/83	4.1	0.5	295	1.6	14.7	739	10.0	5.2	6.0	1087
HV-23-6-1	09/06/83	7.7	2.3	305	1.8	15.7	616	114.0	2.3	6.0	1129
HV-24-5-1	08/06/83	34.0	4.5	440	2.9	0.0	1049	183.0	5.2	2.0	1732
HV-24-6-1	08/06/83	44.0	9.8	390	3.8	0.0	1002	153.0	2.1	6.0	1627
Mean		16.1	2.5	434	2.7	10.5	1008	107.7	3.5	26.8	1589
Standard Deviation		13.2	2.8	86	1.1	16.1	314	102.1	2.2	65.4	393

[a] Symbol: TDS = total dissolved solids.

4.4 WHITEWOOD MINE

In spite of the relatively low concentration of most constituents in the spoil groundwater at Whitewood Mine, the spoil groundwater chemistry represents some very large increases compared to the premining groundwater. The chemical composition of groundwater from unmined surficial sand and gravel and overburden sandstone aquifers have been described by Montreal Engineering (1979). Since the reported composition of groundwater from these two overburden units is virtually identical (Montreal Engineering 1979, Table E-3), for convenience the spoil groundwater chemistry from Whitewood Mine is compared to the mean concentrations of constituents of groundwater from the overburden sand and gravel.

The greatest concentration increases observed in the spoil groundwater are in sulfate, sodium, and TDS. The mean sulfate concentration in the spoil groundwater (178 mg/L) is 35.6 times that in the unmined overburden (5.0 mg/L). Sodium shows a much smaller but still significant increase of 7.5 times in the spoil groundwater (52.2 mg/L vs 7.0 mg/L unmined). The mean TDS concentration in the spoil groundwater represents an increase of 5.9 times that in the unmined overburden (1395 mg/L vs 236 mg/L unmined). If the maximum spoil groundwater salinity is compared with the mean premining TDS concentration, an increase of 7.9 times is observed.

5. SEASONAL VARIATION IN MAJOR ION CHEMISTRY

Six wells at each of three mine sites, Diplomat, Vesta, and Highvale Mines, were sampled on a periodic basis throughout 1983 to evaluate seasonal fluctuations in chemistry. Three wells at each site were located at or just beneath the water table; the remainder were located at or just above the base of the spoil.

In the Battle River mining area, all the deep spoil wells displayed similar behaviour. In all cases, the fluctuations in salinity in these deeper wells were small with the mean difference between minimum and maximum salinity for the year being 650 mg/L or 13.7% of the salinity. The lowest salinity of the year occurred in April, presumably as a result of the spring recharge event. The salinity then increased to maximum values over the summer and fall. In some wells, these higher salinity values remained stable throughout the remainder of the year. In some wells, the salinity decreased in January to values nearly as low as the preceding April.

The behaviour of the water-table wells was more erratic. The same general pattern, with low values of salinity in April, followed by higher values over the summer and fall, which then decrease in December and January, was seen in most wells. Other recharge events, such as individual rainstorms, are reflected in short-lived decreases in salinity during the summer. These variations in chemistry in water-table wells are discussed within the context of individual mine sites below.

At the Highvale Mine site, the wells that showed any pattern at all, displayed behaviour different from that at Battle River. No wells had the April minimum in salinity that was common at Battle River. Four of the six wells were essentially constant throughout the year with salinity minimums in June, August, November, and January. One deep well displayed a relatively erratic variation of about 10% of total salinity around a steady trend. Only one water-table well displayed any trend. In this well, salinity decreased steadily throughout the year from a maximum in April.

5.1 DIPLOMAT MINE

Six wells in the spoil at Diplomat Mine were sampled on a monthly or bi-monthly basis during 1983 to evaluate seasonal variations in spoil groundwater chemistry. Three wells (37-2, 39-3, 40-3) were shallow, completed at the water table, and three were completed deeper in the spoil, including wells 38-1 and 41-1 at the base of the spoil, and well 40-2 in the middle portion of the saturated spoil.

The water-table wells studied ranged in depth from 1 m (39-3) to 5.3 m (40-3). As illustrated in the chemical hydrographs (Figures 34, 35, and 36), the response of groundwater chemistry to seasonal weather conditions is greatest at shallowest depths, and is less pronounced at greater depths. For example, in response to a major precipitation event in late June 1983, well 39-3 (1 m depth) displayed a decrease in TDS of 5300 mg/L, whereas well 37-2 (3 m depth) showed a decrease in TDS of only 100 mg/L and well 40-3 (5.3 m deep) decreased by 900 mg/L.

The general seasonal trend in water chemistry displayed in the water-table wells is for minimum groundwater salinity to occur in the spring, increasing in the summer to a maximum in the late summer or fall, followed by a decline in salinity during late fall or early winter. The magnitude of these seasonal changes, however, is generally relatively small, with the variation in TDS typically on the order of ± 500 to 2000 mg/L.

In the deeper spoil wells, which range from 9.1 m (40-2) to 13.4 m (41-1) in depth, seasonal variations in water chemistry are largely damped out. As shown in Figures 37, 38, and 39, the minimum TDS concentrations occur after snowmelt in April, but thereafter rise slightly to levels that are essentially constant for the remainder of the year. The magnitude of the observed seasonal variation is small, on the order of ± 500 to 700 mg/L TDS, or approximately 10 to 15%.

The longer-term trends in water chemistry, displayed by wells that have been sampled over a period of five years, in all cases indicate that the chemical composition of spoil groundwater

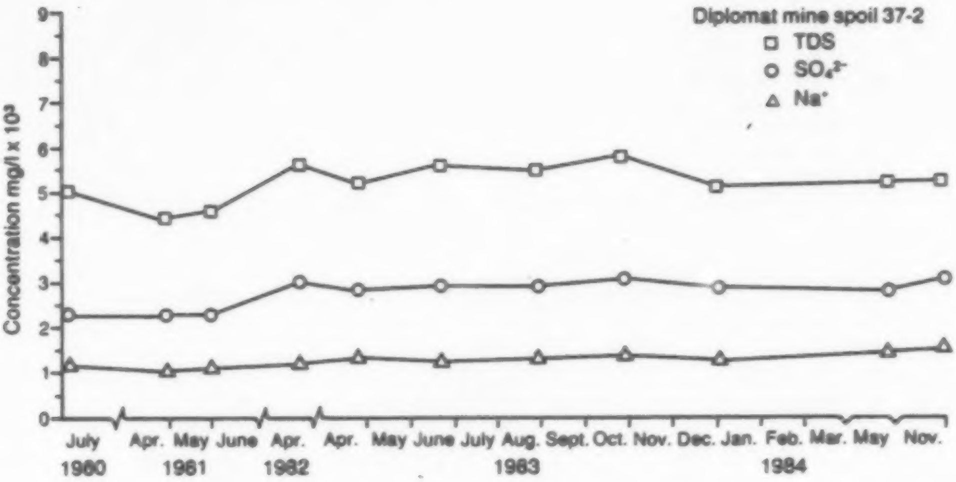


Figure 34. Concentration versus time for piezometer 37-2, Diplomat spoil groundwater.

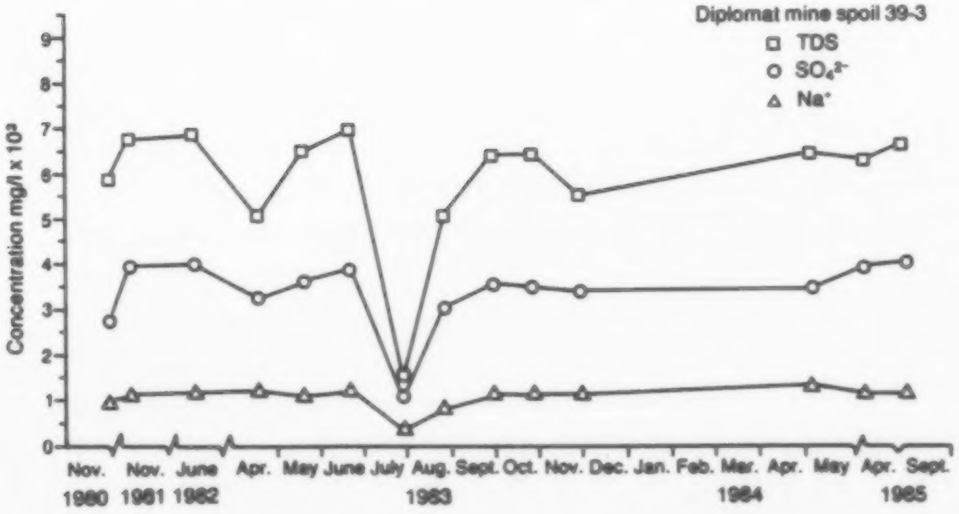


Figure 35. Concentration versus time for piezometer 39-3, Diplomat spoil groundwater.

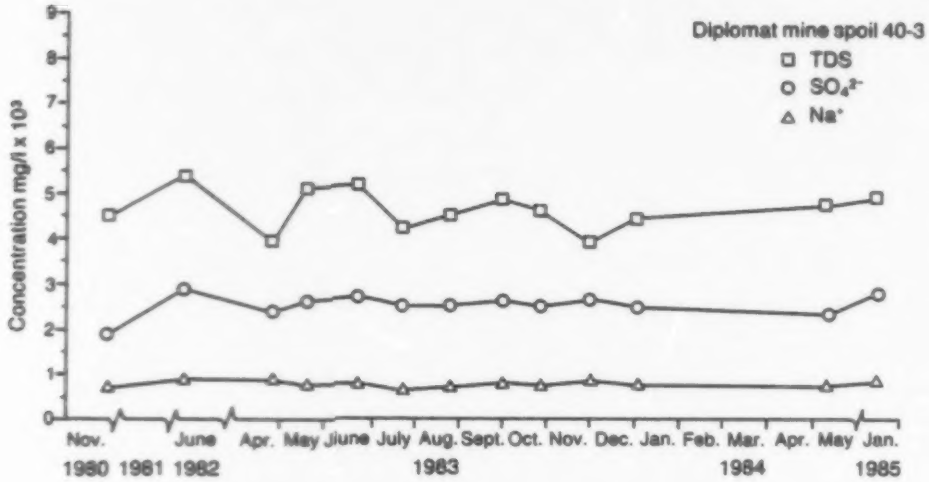


Figure 36. Concentration versus time for piezometer 40-3, Diplomat spoil groundwater.

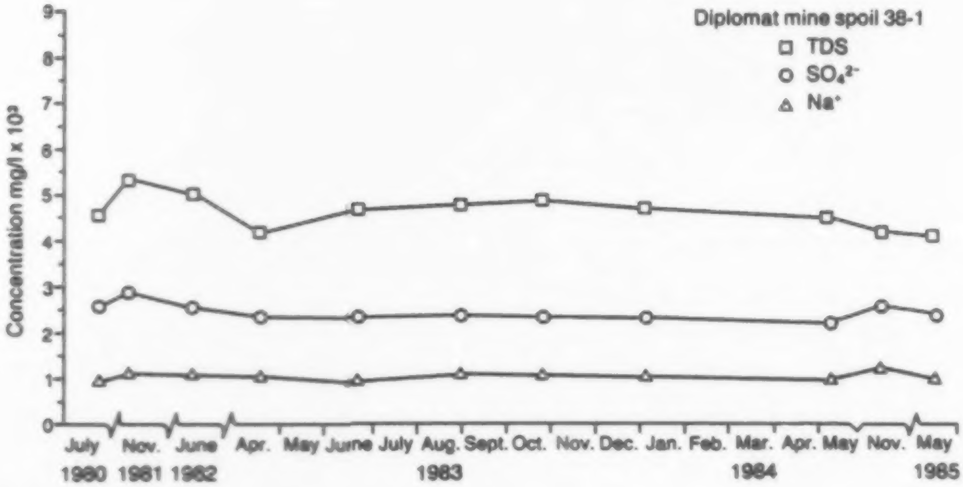


Figure 37. Concentration wersus time for piezometer 38-1, Diplomat spoil groundwater.

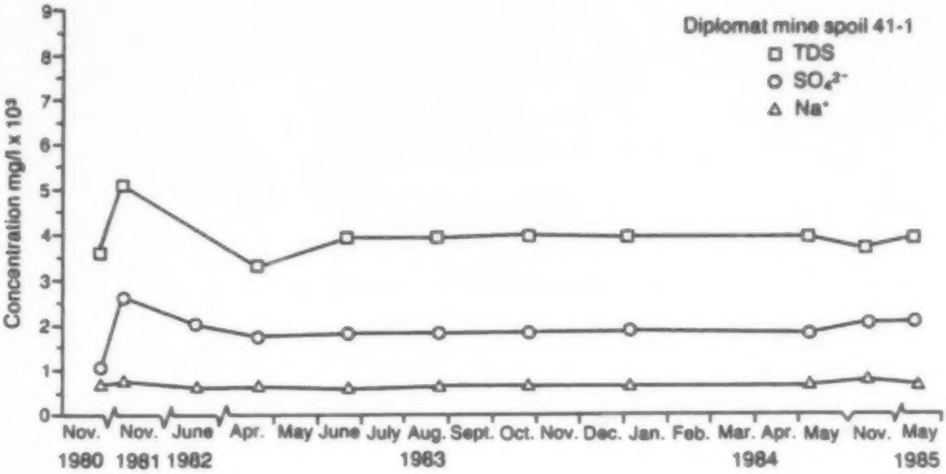


Figure 38. Concentration versus time for piezometer 41-1, Diplomat spoil groundwater.

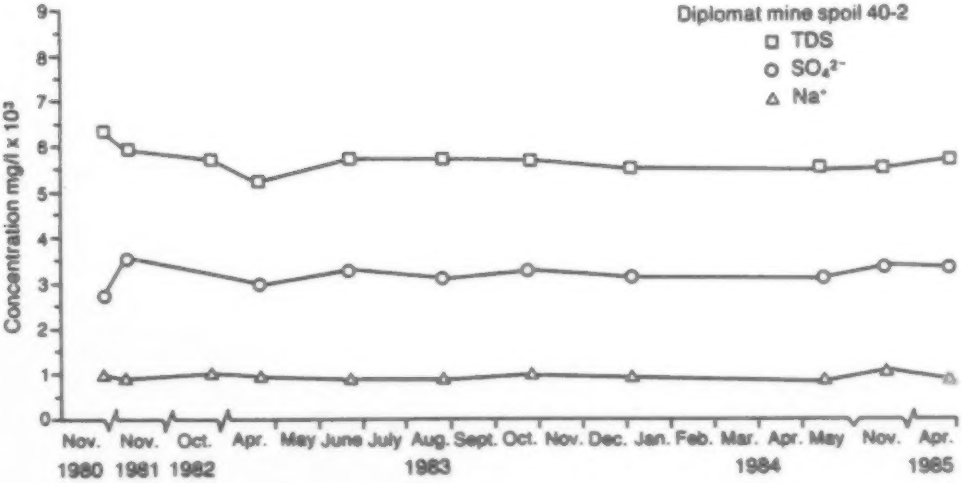


Figure 39. Concentration versus time for piezometer 40-2, Diplomat spoil groundwater.

at Diplomat Mine is stable. Fluctuations have been detected from year to year in most wells, but these fluctuations are generally either within the range of seasonal variation or are not part of a consistent trend. TDS concentrations in well 37-2 were essentially constant between 1980 and 1985, with no net increase or decrease (Figure 34). Sulfate and sodium concentrations in this well were also constant over the period from 1980 to 1985. This pattern was also observed for the other five wells (Figures 35 to 39) at Diplomat Mine. In all cases the concentrations observed in 1984 or 1985 samples were at virtually the same level as in 1980 or 1981.

5.2 VESTA MINE

Six wells in spoil at Vesta Mine were sampled monthly or bi-monthly during 1983 in order to evaluate seasonal variations in water chemistry (Figures 40 to 45). The six wells include three completed at the base of the spoil (43-1, 52-1, and 53-1) with depths ranging from 16.5 to 22.1 m and three water-table wells (53-4, 54-3, and 56-1) at depths from 8.5 to 13.7 m. In almost every case the salinity of the groundwater is lowest immediately after snowmelt in the spring (April), and thereafter increases to maximum levels in summer or fall. This trend toward summer maxima is confirmed by statistical (t-test) analysis of seasonally grouped data, which indicates that TDS concentrations are significantly higher during the summer period (June 16 to September 11 sampling dates), than in the spring (March 21 to June 25 samples), fall (September 12 to December 20 samples), or winter (December 21 to March 20 samples). The magnitude of the seasonal variation in water chemistry tended to be lowest in the deep wells at the base of the spoil, in which two of the three wells (43-1, 52-1) displayed less than 500 mg/L difference between maximum and minimum TDS concentrations over the year. In the remaining deep well (53-1) and two of the water-table wells (53-4, 56-1) the fluctuation in salinity resulting from seasonal effects ranged from 1000 to 1300 mg/L (Figures 43, 44, and 45). This variability represents approximately 15 to 20% of the yearly average

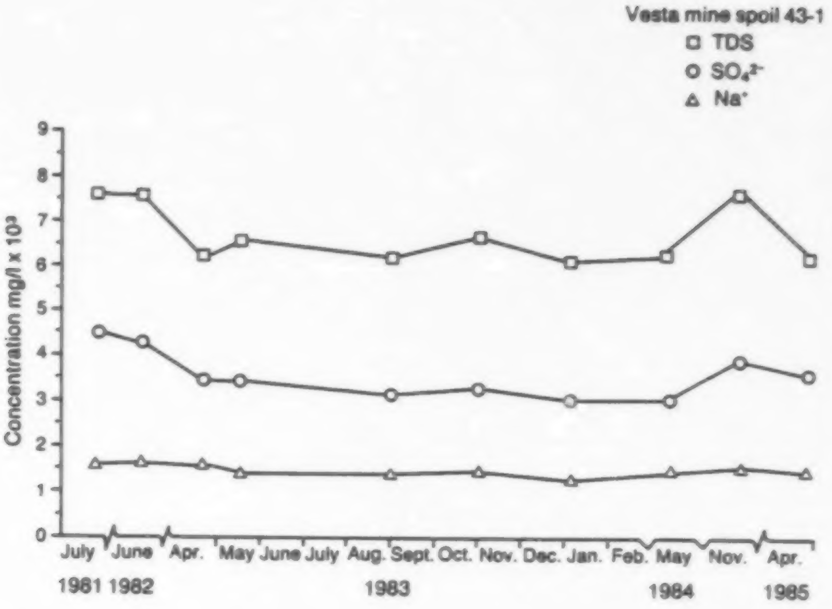


Figure 40. Concentration versus time for piezometer 43-1, Vesta spoil groundwater.

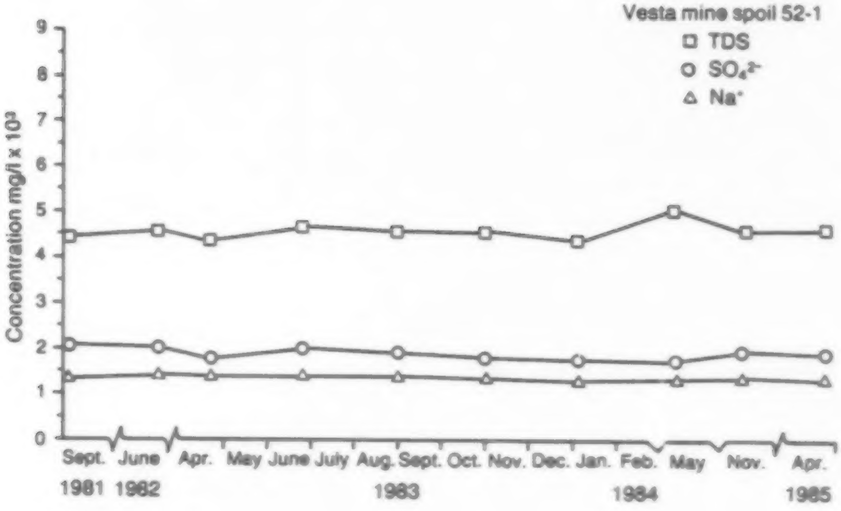


Figure 41. Concentration versus time for piezometer 52-1, Vesta spoil groundwater.

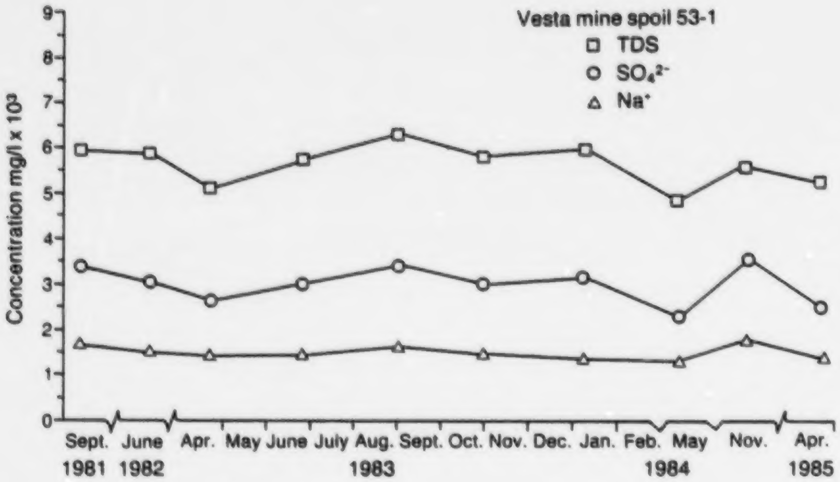


Figure 42. Concentration versus time for piezometer 53-1, Vesta spoil groundwater.

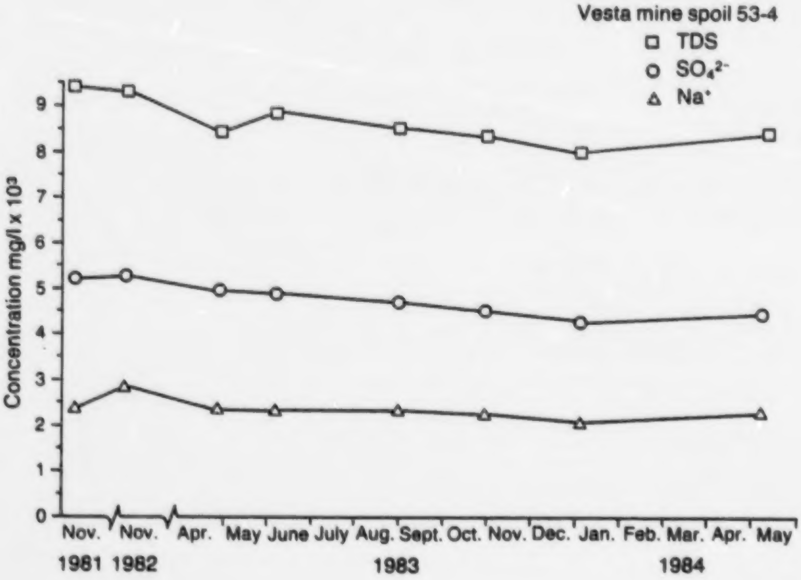


Figure 43. Concentration versus time for piezometer 53-4, Vesta spoil groundwater.

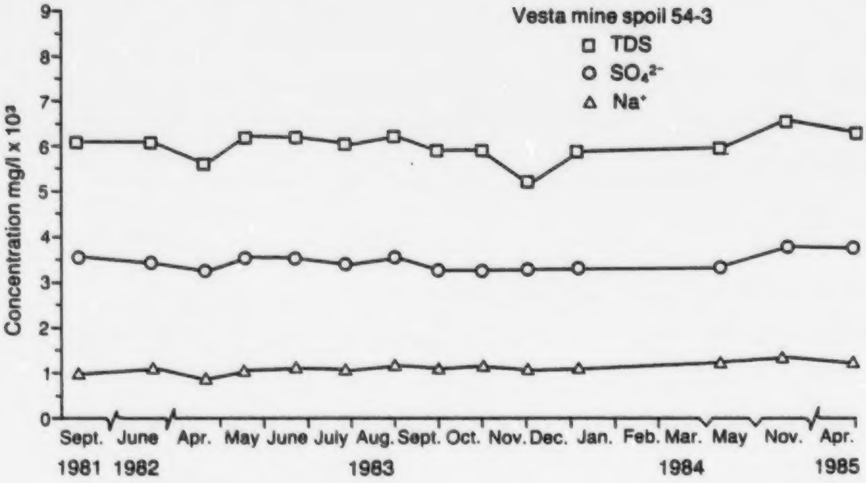


Figure 44. Concentration versus time for piezometer 54-3, Vesta spoil groundwater.

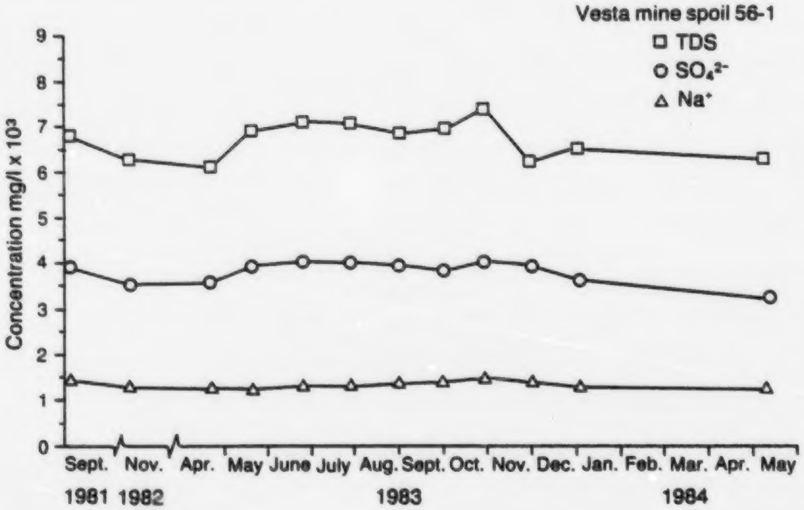


Figure 45. Concentration versus time for piezometer 56-1, Vesta spoil groundwater.

TDS concentration. In the third water-table well (54-3), the salinity is relatively constant, with the maximum variability of just over 800 mg/L corresponding to approximately 10% of the yearly average TDS concentration.

The six wells at Vesta Mine that have been sampled to evaluate seasonal trends in 1983 (as described above) were also sampled between 1980 and 1985. The longer-term trend in spoil groundwater quality indicated by the five-year records are that four of the six wells (42-1, 56-1, 52-1, 53-1) show approximately stable spoil groundwater quality. In one of the remaining two wells (54-3) a trend toward decreasing groundwater salinity was evident between 1981 and 1984, however, the trend reversed in 1985. The TDS, sulfate, and sodium concentrations in April 1985 from this well were approximately the same as in April 1983. In well 53-4 TDS concentrations increased by about 10% per year based on late 1984 and late 1985 samples, over the 1981-1984 baseline TDS levels.

5.3 HIGHVALE MINE

Six piezometers in the spoil at Pit 01 of Highvale Mine were sampled periodically during 1983 to evaluate seasonal changes in spoil groundwater chemistry (Figures 46 to 51). Three of these wells were completed at the water table (HV6-3, 8-4, and 9-2), one was completed in the middle portion of the saturated spoil (HV10-2) and two were completed at the base of the spoil (HV7-1, 12-1). Four of the six wells (HV6-3, 7-1, 8-4, 12-1) showed no clear seasonal trend in groundwater chemistry, as major constituents are essentially constant through the year (Figures 46 to 51). Only one well, HV9-2 (Figure 48), showed a trend toward changing water chemistry through the year, with concentrations peaking in April and declining to minimum levels in November. The chemical characteristics of groundwater from the last well in the group, HV10-2, were variable through the year, although the overall trend shown in Figure 49 represents essentially stable conditions.

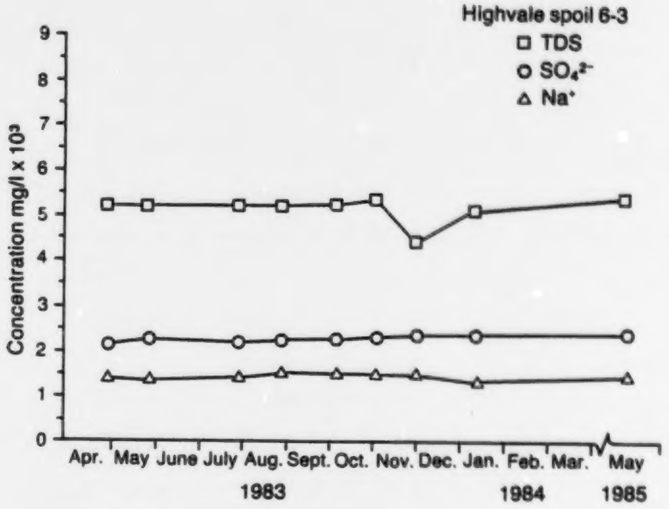


Figure 46. Concentration versus time for piezometer 6-3, Highvale spoil groundwater.

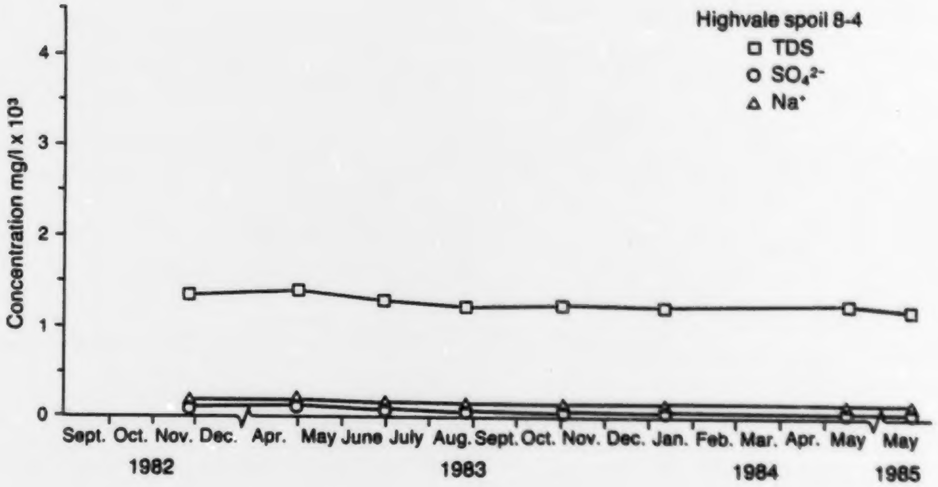


Figure 47. Concentration versus time for piezometer 8-4, Highvale spoil groundwater.

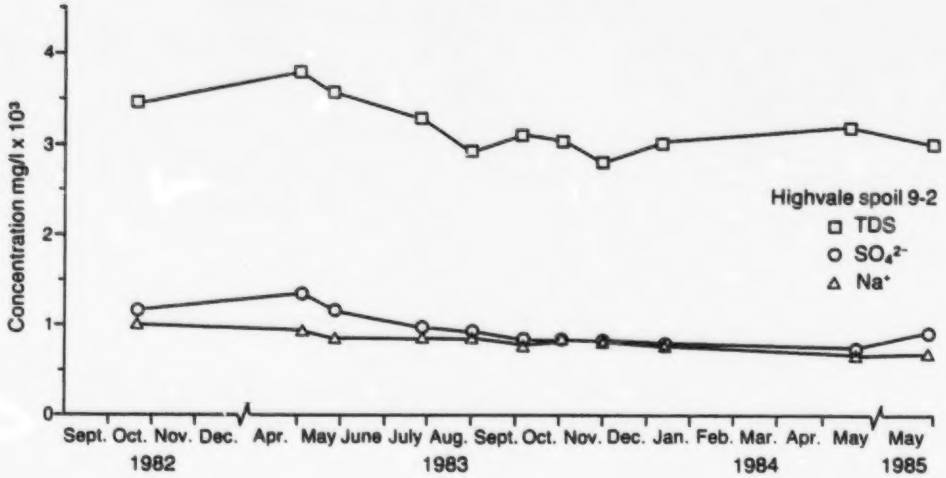


Figure 48. Concentration versus time for piezometer 9-2, Highvale spoil groundwater.

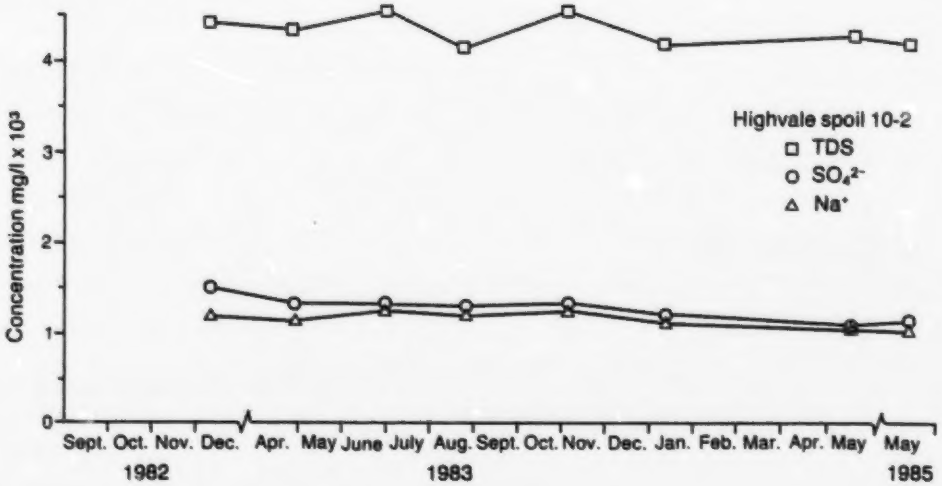


Figure 49. Concentration versus time for piezometer 10-2, Highvale spoil groundwater.

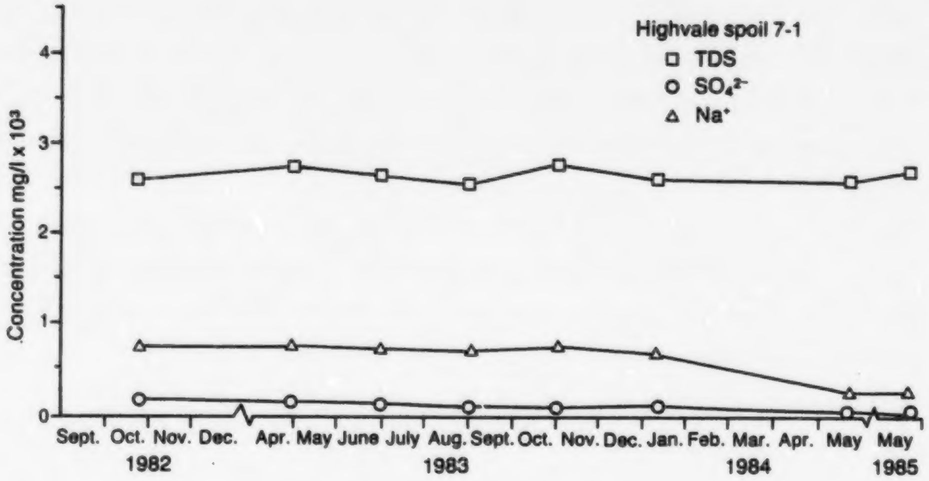


Figure 50. Concentration versus time for piezometer 7-1, Highvale spoil groundwater.

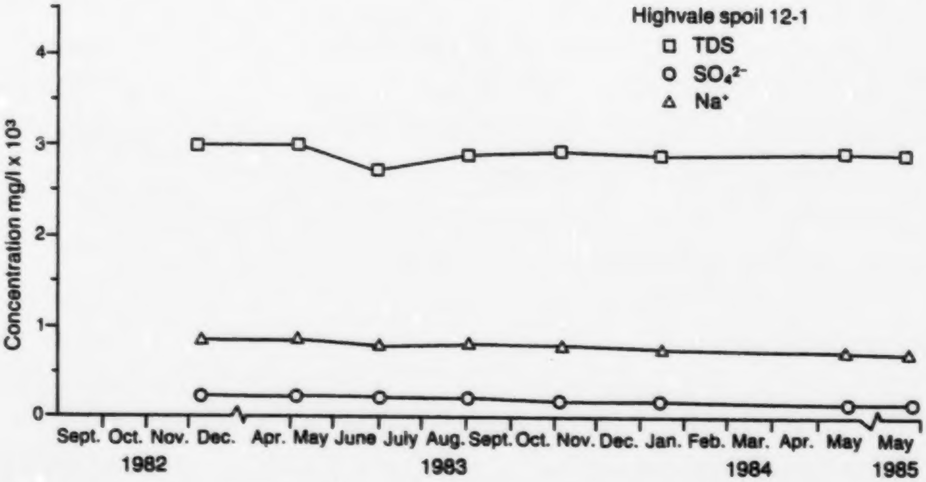


Figure 51. Concentration versus time for piezometer 12-1, Highvale spoil groundwater.

The three-year trend in water chemistry between 1982 and 1985 shown in Figures 46 to 51 indicates that in four of the six wells studied (HV6-3, 7-1, 10-2, 12-1) concentrations of TDS, sulfate, and sodium were essentially constant. In two wells (HV9-2, HV8-4) concentrations tended to decrease with time. In well HV9-2, TDS concentrations decreased by about 3% per year between May 1983 and May 1985. The same pattern is evident in well HV8-4, which shows similar decreases in TDS concentrations between May 1983 and May 1985. Both of these wells are shallow, water-table wells, and may reflect the dilution and/or flushing of the shallow spoil groundwater by recent recharge water. It is anticipated that this flushing trend will continue into the future.

6. TRACE ELEMENT COMPOSITION OF SPOIL GROUNDWATER

Groundwater samples from both spoil and unmined aquifers were analysed for trace and minor constituents, including antimony (Sb), arsenic (As), boron (B), cadmium (Cd), cobalt (Co), copper (Cu), mercury (Hg), lead (Pb), and selenium (Se), as well as total iron (Fe) and sulfide (as H_2S). These species were selected primarily on the basis of their toxicity to humans and animals, as described by McNeely et al. 1979. Iron and sulfide were measured because of their influence on the taste and odour of water, particularly in terms of domestic use.

Table 13 is a summary of the physiological effects associated with each of the trace elements, as well as the recommended maximum concentration for drinking water.

6.1 BATTLE RIVER MINING AREA

Trace element analyses of groundwater samples from Diplomat Mine are listed in Table 14; from Vesta Mine in Table 15; and from the Battle River Bed in Table 16.

Antimony was not detected in any of the groundwater samples from Vesta spoil, Diplomat spoil, or Battle River Bed, at a detection limit of 0.5 ppb.

Arsenic was detected in 90% of Battle River Bed water samples, 88% of Diplomat spoil samples, and 100% of samples from Vesta spoil. The recommended limit of drinking water of 0.050 mg/L was not exceeded by any samples from Battle River Bed, Diplomat spoil, or Vesta spoil. Arsenic in both the Battle River Bed and Diplomat spoil occurs at essentially the same levels (Table 17). The arsenic levels in Vesta spoil and Battle River Bed water had a similar overall average concentration and span approximately the same range of values (Table 17).

Boron was detected in all samples from the Battle River Bed, Diplomat spoil, and Vesta spoil. The recommended limit for crop application of 1.0 mg/L was not exceeded by any samples from the Battle River Bed, but six samples from Diplomat spoil, and one from

Table 13. Summary of trace element characteristics.

Element	Physiological Effects	Recommended Maximum (all values in mg/L except Boron, ppm)	References
Antimony (Sb)	- accumulates in liver - harmful to heart	0.001[a]	Tai 1970
Arsenic (As)	- accumulates in kidneys	0.05[a]	International Joint Commission 1977
Boron (B)	- harmful to Central Nervous System - high concentrations affect plants	5.0[a] 1.0[b]	Department of National Health and Welfare 1979
Cadmium (Cd)	- accumulates in arteries, kidneys and lungs - affects plant growth and suitability as food source	0.005[a]	Department of National Health and Welfare 1979
Cobalt (Co)	- not generally toxic - essential trace nutrient for plants - toxic to some plant species	0.05[b]	Environmental Studies Board 1973
Copper (Cu)	- essential trace nutrient - toxic at high concentrations or after prolonged ingestion	1.00[a]	Department of National Health and Welfare 1979
Lead (Pb)	- toxic to animals and man - accumulates in skeletal material	0.05[b]	Department of National Health and Welfare 1979
Mercury (Hg)	- highly toxic to animals and plants - accumulates in the kidneys and liver	0.002[a]	US Environmental Protection Agency 1970
Selenium (Se)	- may be carcinogenic - accumulates in man and animals - moderately toxic to plants	0.01[a]	Department of National Health and Welfare 1979

[a] Drinking water.

[b] Crop application limit.

Table 14. Diplomat Mine spoil - trace element analyses (all values in mg/L).

Sample ID[a]	As	Cd	Co	Cu	Hg	Pb	Sb	Se	B
Recommended Limit	0.05	0.005	0.05	1.0	0.001	0.05	0.01	0.01	1.00
Detection Limit	0.0004	0.0005	0.0005	0.0005	0.0005	0.0002	0.0005	0.0005	
37-1-1	0.001	0.005	ND[b]	ND	<0.0005	0.002	<0.0005	<0.0005	ND
37-2-2	<0.0004	<0.0005	ND	ND	<0.0005	ND	<0.0005	<0.0005	ND
37-2-3	0.001	ND	0.032	0.002	<0.0005	0.003	<0.0005	<0.0005	0.97
38-1-2	<0.0004	<0.0005	ND	ND	<0.0005	ND	<0.0005	<0.0005	ND
38-1-3	0.001	<0.0005	0.009	0.014	<0.0005	0.003	<0.0005	<0.0005	1.58
39-1-2	0.002	<0.0005	0.018	0.009	<0.0005	0.004	<0.0005	<0.0005	1.03
39-3-3	0.002	<0.0005	0.022	0.014	<0.0005	0.009	<0.0005	<0.0005	0.29
40-1-2	0.001	<0.0005	0.101	0.010	<0.0005	0.002	<0.0005	<0.0005	1.59
40-3-2	0.005	<0.0005	0.016	0.001	<0.0005	0.003	<0.0005	<0.0005	0.51
41-1-3	0.003	<0.0005	0.008	0.020	<0.0005	0.001	<0.0005	<0.0005	1.25
41-3-2	0.004	<0.0005	0.020	0.003	<0.0005	<0.0002	<0.0005	<0.0005	0.66
65-1-1	0.003	<0.0005	0.010	0.009	<0.0005	0.006	<0.0005	<0.0005	1.36
65-2-1	0.006	<0.0005	0.032	0.005	<0.0005	0.019	<0.0005	<0.0005	0.38
66-1-1	0.004	<0.0005	0.016	0.012	<0.0005	0.005	<0.0005	<0.0005	0.72
66-2-1	0.004	<0.0005	0.006	0.001	<0.0005	0.002	<0.0005	<0.0005	0.44
66-3-1	0.004	<0.0005	0.006	0.007	<0.0005	<0.0002	<0.0005	<0.0005	0.27
66-4-1	0.003	<0.0005	0.001	0.007	<0.0005	<0.0002	<0.0005	<0.0005	1.28
Mean	0.003	NA	0.015	0.008	NA[c]	0.004	NA	NA	0.88
Standard Deviation	0.002	NA	0.009	0.006	NA	0.005	NA	NA	0.47

[a] Sample ID represents site number-well number-consecutive sampling number.
[b] ND: No data available.
[c] NA: Not applicable.

Table 15. Vesta Mine spoil - trace element analyses (all values in mg/L).

Sample ID[a]	As	Cd	Co	Cu	Hg	Pb	Sb	Se	B
Recommended Limit	0.05	0.005	0.05	1.0	0.001	0.05	0.01	0.01	1.00
Detection Limit	0.0004	0.0005	0.0005	0.0005	0.0005	0.0002	0.0005	0.0005	
42-1-2	ND[b]	0.001	ND	ND	0.0005	0.001	<0.0005	ND	0.67
42-1-3	0.003	<0.0005	0.007	0.001	<0.0005	0.001	<0.0005	<0.0005	0.70
42-2-1	ND	<0.0005	ND	ND	<0.0005	0.0002	<0.0005	ND	0.87
42-3-1	ND	0.001	ND	ND	<0.0005	0.000	<0.0005	ND	0.79
42-3-2	0.005	<0.0005	0.013	0.004	<0.0005	0.002	<0.0005	0.005	0.41
43-1-1	ND	0.001	ND	ND	<0.0005	0.001	<0.0005	ND	0.75
43-1-2	0.001	0.004	0.046	0.004	<0.0005	0.003	<0.0005	<0.0005	0.56
43-2-1	ND	<0.0005	ND	ND	<0.0005	0.002	<0.0005	ND	ND
43-2-2	0.005	<0.0005	0.054	0.005	<0.0005	0.004	<0.0005	<0.0005	0.64
52-1-1	0.003	0.001	ND	ND	<0.0005	0.003	<0.0005	ND	0.51
52-1-2	0.001	<0.0005	0.013	0.002	<0.0005	0.002	<0.0005	ND	0.53
52-2-1	0.002	0.001	ND	ND	<0.0005	0.001	<0.0005	ND	0.30
52-3-1	0.005	0.001	ND	ND	<0.0005	0.001	<0.0005	ND	0.30
52-3-2	0.004	<0.0005	0.014	0.002	<0.0005	<0.0002	<0.0005	<0.0005	0.31
52-4-1	0.001	0.001	ND	ND	<0.0005	0.001	ND	ND	0.33
52-4-2	0.005	<0.0005	0.012	0.004	<0.0005	<0.0002	<0.0005	<0.0005	0.34
53-1-1	0.007	0.001	ND	ND	<0.0005	0.003	<0.0005	ND	0.63
53-1-2	0.002	<0.0005	0.013	0.001	<0.0005	<0.0002	<0.0005	<0.0005	0.53
53-2-1	0.005	0.001	ND	ND	<0.0005	0.001	<0.0005	ND	0.24
53-2-2	0.003	<0.0005	0.019	0.007	<0.0005	0.001	<0.0005	<0.0005	0.24
53-3-1	0.009	0.001	ND	ND	<0.0005	ND	<0.0005	ND	0.26
53-3-2	0.005	<0.0005	0.16	0.003	<0.0005	0.002	<0.0005	<0.0005	0.26
53-4-1	0.003	0.001	ND	ND	<0.0005	0.001	<0.0005	ND	0.24
53-4-2	0.004	<0.0005	0.022	0.001	<0.0005	0.004	<0.0005	<0.0005	0.22
53-5-1	0.001	0.001	ND	ND	<0.0005	0.001	<0.0005	ND	0.17
53-5-2	0.001	<0.0005	0.014	0.004	<0.0005	0.006	<0.0005	<0.0005	0.16
54-1-2	0.003	<0.0005	0.003	0.004	<0.0005	0.003	<0.0005	<0.0005	1.23
55-1-1	0.003	0.001	ND	ND	<0.0005	0.004	<0.0005	ND	0.49
55-2-1	0.004	<0.0005	ND	ND	<0.0005	0.002	<0.0005	ND	ND
55-3-1	0.006	<0.0005	ND	ND	<0.0005	0.001	<0.0005	ND	0.34
55-4-1	0.003	<0.0005	ND	ND	<0.0005	0.001	<0.0005	ND	0.45
55-5-1	0.005	0.002	ND	ND	<0.0005	0.007	<0.0005	ND	0.64
55-6-1	0.004	0.001	ND	ND	ND	0.001	<0.0005	ND	0.92
56-1-1	0.006	0.001	ND	ND	ND	0.001	ND	ND	0.88
Mean	0.004	0.001	0.023	0.005	NA[c]	0.002	NA	NA	0.48
Standard Deviation	0.002	0.0008	0.017	0.005	NA	0.0017	NA	NA	0.27

[a] Sample ID represents site number-well number-consecutive sampling number.
[b] ND: No data available.
[c] NA: Not applicable.

Table 16. Battle River Bed - trace element analyses (all values in mg/L).

Sample ID[a]	As	Cd	Co	Cu	Hg	Pb	Sb	Se	B
Recommended Limit	0.050	0.005	0.050	1.00	0.001	0.050	0.01	0.010	1.00
Detection Limit	0.0004	0.0005	0.0005	0.0005	0.0005	0.0002	0.0005	0.0005	
2-2-1	0.0060	<0.0005	ND[b]	0.0040	<0.0005	0.0010	<0.0005	<0.0005	ND
5-2-1	ND	0.001	ND	0.0020	<0.0005	0.0030	<0.0005	<0.0005	0.76
16-5-1	0.0017	<0.0005	0.0013	0.0092	<0.0005	0.0006	<0.0005	<0.0005	0.56
17-3-1	0.001	0.002	ND	0.0050	<0.0005	0.0030	<0.0005	<0.0005	0.65
24-3-1	0.0034	<0.0005	<0.0005	0.0057	<0.0005	0.0019	0.0019	<0.0005	0.82
24-6-1	0.001	0.001	ND	0.0070	<0.0005	0.0040	<0.0005	<0.0005	ND
45-1-1	0.006	<0.0005	ND	0.0520	<0.0005	0.0100	<0.0005	0.001	0.38
45-2-1	0.0046	<0.0005	0.0021	0.0042	<0.0005	0.0013	<0.0005	<0.0005	0.55
45-3-1	0.0040	<0.0005	0.0025	0.0046	<0.0005	0.0009	<0.0005	0.00009	0.57
47-2-1	<0.0005	<0.0005	ND	<0.0005	<0.0005	0.0010	<0.0005	<0.0005	0.63
Mean	0.003	NA	0.0015	0.009	NA[c]	0.0027	NA	NA	0.62
Standard Deviation	0.002	NA	0.0011	0.015	NA	0.0028	NA	NA	0.14

[a] Sample ID represents - site number-well number-consecutive sampling number.
[b] ND: No data available.
[c] NA: Not applicable.

Table 17. Summary of trace element analyses, Battle River mining area.

Diplomat

	Mean	SD	Range	Number Analysed	Number Detected	Number Exceedin Recommended Limi
As	0.003	0.002	<0.0004 to 0.006	17	15	0
Cd	NA[a]	NA	<0.0005 to 0.005	16	1	0
Co	0.015	0.009	0.001 to 0.101	14	14	1
Cu	0.008	0.006	0.001 to 0.020	14	14	0
Hg	NA	NA	NA	17	0	0
Pb	0.0038	0.0047	<0.0002 to 0.019	15	12	0
Sb	NA	NA	NA	17	0	0
Se	NA	NA	NA	17	0	0
B	0.88	0.47	0.29 to 1.59	14	14	6

Vesta

	Mean	SD	Range	Number Analysed	Number Detected	Number Exceedin Recommended Limit
As	0.004	0.002	0.001 to 0.009	29	29	0
Cd	0.001	0.0008	<0.0005 to 0.004	34	17	0
Co	0.023	0.017	0.003 to 0.16	13	13	2
Cu	0.005	0.005	0.001 to 0.007	13	13	0
Hg	NA	NA	NA	32	0	0
Pb	0.002	0.0017	<0.0002 to 0.007	33	30	0
Sb	NA	NA	NA	33	0	0
Se	NA	NA	<0.0005 to 0.005	12	1	0
B	0.48	0.27	0.16 to 1.23	32	32	1

Battle River Bed

	Mean	SD	Range	Number Analysed	Number Detected	Number Exceeding Recommended Limit
As	0.003	0.002	<0.0005 to 0.006	9	8	0
Cd	NA	NA	<0.0005 to 0.002	10	3	0
Co	0.0015	0.0011	<0.0005 to 0.0025	4	4	0
Cu	0.009	0.015	<0.0005 to 0.052	10	9	0
Hg	NA	NA	NA	10	0	0
Pb	0.0027	0.0028	0.0006 to 0.01	10	10	0
Sb	NA	NA	<0.0005 to 0.0019	10	1	1
Se	NA	NA	<0.0005 to 0.001	10	1	0
B	0.62	0.14	0.38 to 0.82	8	8	0

[a] NA: Not applicable.

Vesta spoil exceeded the limit. The concentration of boron in Diplomat groundwater is slightly higher and more variable than in groundwater from the Battle River Bed (Tables 14, 16, and 17). The average concentration of boron in Vesta spoil groundwater is slightly lower and more variable than the unmined coal (Tables 15, 16, and 17).

Cadmium was detected in 30% of the Battle River Bed samples, 6% of the samples from Diplomat spoil, and 50% of samples from Vesta spoil. The recommended limit for drinking water of 5.0 ppb was not exceeded by any of the samples from the Battle River Bed, Vesta spoil, or Diplomat spoil. The occurrence of cadmium was highest in groundwater samples from Vesta Mine. Cadmium was detected in two Diplomat spoil groundwater samples at concentrations of 0.005 and 0.002 mg/L. Cadmium was detected in three samples from the Battle River Bed, at concentrations of 0.001, 0.001, and 0.002 mg/L.

Cobalt was detected in all of the samples from Battle River Bed, Vesta spoil, and Diplomat spoil (Tables 14, 15, and 16). The recommended limit of cobalt concentration for irrigation water purposes of 50 ppb was not exceeded by any samples from Battle River Bed. However, two samples from Vesta and one sample from Diplomat exceeded the recommended limit. In comparison of data from the Battle River Bed and Diplomat spoil groundwater samples, the mean concentration of cobalt in the Diplomat spoil is 10 times higher than Battle River Bed samples (Table 17). The data indicate a mean concentration of cobalt in Vesta spoil that is more than 15 times that of the Battle River Bed (Table 17).

Copper was detected in all groundwater samples from Diplomat and Vesta spoil, and in 90% of samples from the Battle River Bed (Tables 14, 15, and 16). The objective concentration for copper for drinking water purposes of 0.01 mg/L was exceeded by five samples from Diplomat, one sample from Battle River Bed, but was not exceeded by any samples from Vesta spoil. The data indicate that the water in the Battle River Bed has an overall concentration of copper that is slightly higher than the Diplomat spoil groundwater, and copper concentrations in the coal are more variable than in the spoil (Tables 14, 16, and 17). The average concentration of copper in the groundwater from the Battle River Bed is 1.6 times higher than samples from the spoil at Vesta Mine (Table 17).

Lead was detected in all samples from Battle River Bed, 91% of samples from Vesta spoil, and 80% of samples from Diplomat spoil at a detection limit of 0.0002 mg/L. The recommended concentration limit of lead for drinking water purposes of 0.05 mg/L was not exceeded by any samples from Diplomat spoil, Vesta spoil, or the Battle River Bed. A comparison of the lead analyses from Diplomat spoil and Battle River Bed groundwater indicates that the lead concentration in the coal is slightly higher than in Diplomat spoil groundwater. Lead levels in Vesta spoil groundwater and the Battle River Bed were essentially the same.

None of the samples from Diplomat spoil, Vesta spoil, or Battle River Bed exceeded the recommended limit for mercury for drinking water of 0.001 mg/L. In fact, mercury was not detected at a level of 0.0005 mg/L in any of the samples.

Selenium, at a detection limit of 0.0005 mg/L, was only detected in one sample from the Battle River Bed and one sample from Vesta spoil. None of the samples from any of the three units exceeded the recommended limit for drinking water of 0.01 mg/L.

Iron, at a detection limit of 0.01 mg/L, was detected in 94% of samples from Diplomat spoil, 97% of samples from Vesta spoil, and 97% of the samples from Battle River Bed (Tables 18, 19, and 20). The acceptable level for iron for drinking water purposes of 0.3 mg/L was exceeded by 47% of samples from Diplomat spoil, by 51% of samples from Vesta spoil, and by 3.4% of samples from the unmined coal. The concentration of iron in the Battle River Bed ranged from less than 0.01 to 0.4 mg/L, with a mean value of 0.09 mg/L, and a standard deviation of 0.08. Iron values in the Diplomat spoil water ranged from less than 0.01 to 4.8 mg/L, had a mean value of 0.81 mg/L, and a standard deviation of 1.08. This indicates that the concentration of iron in the Diplomat Mine spoil groundwater is almost nine times that

Table 18. Diplomat Mine spoil - iron and sulfide analyses (all values in mg/L).

Sample ID	Fe	S	Sample ID	Fe	S
Recommended Limit				0.30	0.300
Detection Limit				0.01	0.001
37-2-1	1.75	0.000	39-1-2	0.027	0.003
37-3-1	0.18	0.000	40-1-2	0.96	0.010
38-1-1	0.21	0.000	39-3-3	0.17	0.003
39-1-1	0.42	0.010	65-1-1	0.069	0.007
39-3-1	0.00	0.000	65-2-1	0.31	0.010
40-1-1	0.19	0.000	63-2-1	0.81	0.000
40-2-1	1.12	0.005	63-1-1	0.37	0.013
40-3-1	0.16	0.010	63-3-1	0.73	0.012
41-1-1	0.10	0.030	51-2-2	0.03	0.003
41-2-1	0.09	0.030	64-4-1	1.50	0.011
51-1-1	0.30	0.030	65-3-1	0.25	0.004
37-1-1	0.10	0.000	40-2-3	2.20	0.000
37-1-2	0.00	0.012	39-2-2	0.27	0.013
37-2-2	ND[a]	0.000	41-2-2	1.70	0.003
37-2-3	0.08	0.000	51-1-2	0.08	0.009
38-1-2	0.22	0.000	64-2-1	0.27	0.011
39-2-1	1.16	0.020	64-3-1	2.24	0.000
40-2-2	3.80	0.010	64-1-1	0.55	0.003
41-1-2	ND	0.000	37-1-3	1.20	0.003
41-3-1	0.00	0.000	71-2-1	0.20	0.012
66-4-1	0.80	0.016	67-1-1	4.80	0.013
38-1-3	0.26	0.000	37-2-4	0.06	ND
41-1-3	1.40	0.008	71-3-1	0.69	0.000
40-3-2	ND	0.000	69-2-1	0.17	0.012
66-3-1	ND	0.016	69-1-1	0.69	0.000
66-2-1	3.80	0.004	67-3-1	ND	0.340
41-3-2	0.67	0.000	67-2-1	0.30	0.000
Mean				0.81	0.013
Standard Deviation				1.08	0.046

[a] ND: No data available.

Table 19. Vesta Mine spoil - iron and sulfide analyses (all values in mg/L).

Sample ID	Fe	S	Sample ID	Fe	S
Recommended Limit				0.30	0.300
Detection Limit				0.01	0.001
42-1-1	0.00	0.000	55-4-1	0.79	0.019
42-1-2	0.11	0.020	56-1-1	0.62	0.005
42-3-1	0.04	0.001	52-2-2	0.06	0.018
43-1-1	2.04	0.002	53-1-2	0.06	0.022
52-1-1	0.07	0.002	52-4-2	0.07	0.009
52-2-1	0.69	0.010	52-3-2	0.18	0.019
52-3-1	0.18	0.015	52-1-2	0.06	ND[a]
52-4-1	0.51	0.012	53-5-2	0.55	0.001
53-1-1	0.30	0.073	53-4-2	1.25	0.003
53-2-1	0.15	0.021	42-3-2	0.08	0.010
53-3-1	0.47	0.000	42-1-3	0.012	0.010
53-4-1	0.82	0.011	43-1-2	ND	0.000
53-5-1	0.46	0.002	53-2-2	0.86	0.028
54-1-1	0.04	0.011	53-3-2	0.90	0.002
54-2-1	0.48	0.008	54-1-2	0.01	0.022
55-1-1	1.19	0.005	42-2-2	0.24	0.000
55-2-1	2.60	0.016	56-1-2	0.85	0.000
55-3-1	3.80	0.019	55-1-1	1.19	0.005
Mean				0.62	0.011
Standard Deviation				0.81	0.013

[a] ND: No data available.

Table 20. Battle River Bed - iron and sulfide analyses (all values in mg/L).

Sample ID	Fe	S	Sample ID	Fe	S
Recommended Limit				0.30	0.300
Detection Limit				0.01	0.001
4-2-1	0.24	0.075	32-2-2	0.20	0.000
6-3-1	0.25	0.032	2-2-1	0.04	0.015
8-2-1	0.06	0.005	15-2-2	0.09	1.020
8-2-2	0.06	0.000	17-3-1	0.02	0.030
9-4-1	0.01	0.000	45-1-1	0.05	0.002
9-4-2	0.08	0.000	75-1-1	0.05	0.003
12-2-1	0.01	0.018	74-1-1	0.10	0.042
14-2-1	0.07	0.000	77-1-1	0.17	0.002
14-2-2	0.05	0.011	16-5-1	0.08	0.032
15-2-1	0.04	0.009	24-3-1	0.05	0.014
20-3-1	0.06	0.016	7-2-1	ND[a]	0.001
23-3-1	0.14	0.029	25-3-1	0.08	0.016
28-2-1	0.07	0.000	45-2-1	0.07	0.004
29-3-1	0.09	0.023	45-3-1	0.07	0.031
32-2-1	0.40	0.000	76-1-1	0.06	0.033
Mean				0.09	0.049
Standard Deviation				0.08	0.184

[a] ND: No data available.

of the unmined coal, and is much more variable. The concentration of iron in Vesta spoil water samples ranged from less than 0.01 to 3.8 mg/L, with a mean concentration of 0.62 mg/L and a standard deviation of 0.81. The concentration of iron in the Vesta spoil is therefore more than five times that of the unmined coal, and varies over a much wider range of values.

Sulfide, at a detection limit of 0.001 mg/L, was detected in 77% of samples from the Battle River Bed, 86% of samples from Vesta spoil, and 62% of samples from Diplomat spoil (Tables 18, 19, and 20). The acceptable level of 0.3 mg/L sulfide for public drinking water was not exceeded by any samples from Vesta spoil. However, one sample from Diplomat Mine, and one sample from the Battle River Bed exceeded the limit. The concentration of sulfide in Diplomat Mine spoil water ranged from less than 0.001 to 0.34 mg/L, with a mean concentration of 0.013 mg/L, and a standard deviation of 0.046. The concentration of sulfide in the Battle River Bed water ranged from less than 0.001 to 1.02 mg/L, with a mean value of 0.049 mg/L, and a standard deviation of 0.184. A comparison of sulfide data from the unmined coal and Diplomat Mine groundwater indicates that the sulfide concentration of the coal is almost 4 times that of the Diplomat spoil. The concentration of sulfide in the Vesta Mine ranged from less than 0.001 to 0.073 mg/L, with a mean concentration of 0.011 mg/L and a standard deviation of 0.013. This indicates that the concentration of sulfide in the Battle River Bed is more than four times that of Vesta Mine.

6.2 LAKE WABAMUN MINING AREA

Trace element analyses of groundwater samples from the spoil at Highvale Mine (Pit 01), overburden sandstone at Highvale Mine, and Whitewood Mine spoil are listed in Tables 21, 22, and 23, respectively, and summarized in Table 24.

Antimony was not detected in any of Highvale spoil or Whitewood spoil groundwater samples, or Highvale overburden sandstone sample at a detection limit of 0.0005 mg/L.

Table 21. Highvale spoil - trace element analyses (all values in mg/L).

Sample ID	As	Cd	Co	Cu	Hg	Pb	Sb	Se	B
Recommended Limit	0.05	0.005	0.05	1.0	0.001	0.05	0.01	0.01	1.00
Detection Limit	0.0004	0.0005	0.0005	0.0005	0.0005	0.0002	0.0005	0.0005	
HV-2-1-1	0.0036	<0.0005	0.0010	0.0165	<0.0005	<0.0002	<0.0005	<0.0005	0.20
HV-2-2-1	0.0074	<0.0005	0.0027	0.0130	<0.0005	0.0005	<0.0005	<0.0005	0.17
HV-3-1-1	0.0031	<0.0005	0.0010	0.0055	<0.0005	0.0014	<0.0005	<0.0005	0.54
HV-4-1-1	0.0150	<0.0005	0.0010	0.0148	<0.0005	0.0004	<0.0005	<0.0005	0.19
HV-6-1-1	0.315	0.0016	<0.0005	0.0330	<0.0005	0.0085	<0.0005	<0.0005	0.24
HV-6-2-1	0.0076	0.0006	<0.0005	0.0120	<0.0005	<0.0002	<0.0005	<0.0005	0.26
HV-6-3-1	0.030	<0.0005	<0.0005	0.0130	<0.0005	<0.0002	<0.0005	<0.0005	0.24
HV-7-1-1	0.0046	<0.0005	0.0020	0.0140	<0.0005	0.0005	<0.0005	<0.0005	0.18
HV-7-2-1	0.0064	<0.0005	0.0020	0.0082	<0.0005	0.0010	<0.0005	<0.0005	0.32
HV-8-2-1	0.0026	<0.0005	0.0010	0.0073	<0.0005	<0.0002	<0.0005	<0.0005	0.17
HV-8-3-1	0.0230	<0.0005	0.0400	0.0100	<0.0005	0.0024	<0.0005	<0.0005	0.70
HV-8-4-1	0.0120	<0.0005	0.0105	0.0045	<0.0005	0.0006	<0.0005	<0.0005	0.08
HV-9-1-1[a]	0.1900	<0.0005	<0.0005	0.0230	<0.0005	<0.0002	0.0035	0.165	4.00
HV-10-1-1	0.0043	<0.0005	0.0025	0.0082	<0.0005	<0.0002	<0.0005	<0.0005	0.18
HV-10-3-1	0.0065	0.0008	0.0080	0.0440	<0.0005	0.0005	<0.0005	<0.0005	0.18
HV-11-1-1	0.0056	<0.0005	<0.0005	0.0090	<0.0005	<0.0002	<0.0005	<0.0005	0.14
HV-11-2-1	0.0018	<0.0008	0.0140	0.0800	<0.0005	<0.0002	<0.0005	<0.0005	0.08
HV-11-3-1	0.0020	0.0005	0.0035	0.0580	<0.0005	0.0115	<0.0005	<0.0005	0.10
HV-12-1-1	0.0026	<0.0005	<0.0005	0.0044	<0.0005	<0.0002	<0.0005	<0.0005	0.33
HV-14-1-1	0.0034	<0.0005	<0.0005	<0.0005	<0.0005	0.0012	<0.0005	<0.0005	ND[b]
HV-14-2-1	0.0020	0.001	0.0025	0.0038	<0.0005	0.0006	<0.0005	<0.0005	ND
Mean	0.0074	0.0009	0.0066	0.0191	NA[b]	0.0024	NA	NA	0.16
Standard Deviation	0.0077	0.0004	0.0104	0.0200	NA	0.0036	NA	NA	0.24
N[b]	21	5	14	20	0	12	1	1	19

[a] Well completed in ash.

[b] Symbol: N = number of samples detected; NA = not applicable.

Table 22. Highvale overburden sandstone - trace element analyses (all values in mg/L).

Sample ID	As	Cd	Co	Cu	Hg	Pb	Sb	Se	B
Recommended Limit	0.05	0.005	0.05	1.0	0.001	0.05	0.01	0.01	1.0
Detection Limit	0.0004	0.0005	0.0005	0.0005	0.0005	0.0002	0.0005	0.0005	
HE77-3-1-1	0.0085	<0.0005	0.0007	0.0065	<0.0005	0.0012	<0.0005	<0.0005	ND[a]
HE77-4-1-1	0.0007	<0.0005	0.0017	0.0012	<0.0005	0.0008	<0.0005	<0.0005	0.63
HV-16-1-1	0.0012	<0.0005	0.0030	0.0115	<0.0005	0.0015	<0.0005	0.0005	ND
HV-16-2-1	0.0023	<0.0005	0.0030	0.0060	<0.0005	0.0015	<0.0005	<0.0005	ND
HV-16-3-1	0.0025	<0.0005	0.0040	0.0060	<0.0005	0.0027	<0.0005	<0.0005	ND
HV-17-4-1	<0.0005	<0.0005	0.0020	0.0050	<0.0005	<0.0005	<0.0005	<0.0005	ND
HV-19-2-1	0.0070	<0.0005	0.0008	0.0030	<0.0005	0.0013	<0.0005	<0.0005	ND
HV-21-1-1	0.0120	<0.0005	<0.0005	0.0030	<0.0005	<0.0002	<0.0005	<0.0005	ND
HV-22-1-1	0.0060	<0.0005	<0.0005	0.0085	<0.0005	0.0014	<0.0005	<0.0005	ND
HV-23-5-1	0.0095	<0.0005	0.0009	0.0145	<0.0005	<0.0002	<0.0005	<0.0005	ND
HV-24-5-1	0.0013	<0.0005	0.0032	0.0029	<0.0005	0.0027	<0.0005	<0.0005	ND
HV-24-6-1	0.0015	<0.0005	0.0020	0.0018	<0.0005	0.0011	<0.0005	<0.0005	ND
KE78-11-1-1	0.0028	<0.0005	0.0017	0.0010	<0.0005	0.0020	<0.0005	<0.0005	ND
KE78-11-2-1	0.0005	<0.0005	0.0015	0.0007	<0.0005	0.0040	<0.0005	<0.0005	ND
KE78-11-3-1	0.0004	<0.0005	<0.0005	0.0007	<0.0005	0.0012	<0.0005	<0.0005	ND
SB81-1-2-1	0.0028	<0.0005	<0.0005	0.0012	<0.0005	0.0010	<0.0005	<0.0005	ND
SB81-2-3-1	0.0024	<0.0005	0.0005	0.0005	<0.0005	0.0004	<0.0005	<0.0005	ND
Mean	0.0047	NA[b]	0.0019	0.0042	NA	0.0016	NA	NA	NA
Standard Deviation	0.0045	NA	0.0011	0.0040	NA	0.0009	NA	NA	NA

[a] ND: No data available.
[b] NA: Not applicable.

Table 23. Whitewood spoil - trace element analyses (all values in mg/L).

Sample ID	As	Cd	Co	Cu	Hg	Pb	Sb	Se	B
Recommended Limit	0.05	0.005	0.05	1.0	0.001	0.05	0.01	0.01	1.00
Detection Limit	0.0004	0.0005	0.0005	0.0005	0.0005	0.0002	0.0005	0.0005	
WW-2A-1	0.0008	<0.0005	0.0012	0.0007	<0.0005	0.0005	<0.0005	<0.0005	0.12
WW-4-1-1	0.0024	0.0009	0.0035	0.0005	<0.0005	0.0005	<0.0005	<0.0005	0.12
WW-4A-1	0.0020	0.0009	<0.0005	0.0022	<0.0005	0.0006	<0.0005	<0.0005	0.19
WW-4B-1	0.0035	0.0009	0.0530	0.0025	<0.0005	0.0006	<0.0005	<0.0005	0.85
WW-4C-1	0.0026	0.0009	0.0007	0.0005	<0.0005	<0.0002	<0.0005	<0.0005	0.13
WW-5C-1	0.0011	<0.0005	0.0016	0.0013	<0.0005	0.0005	<0.0005	<0.0005	0.20
WW-6A-1	0.0140	<0.0005	0.0105	0.0009	<0.0005	<0.0002	<0.0005	<0.0005	ND[a]
WW-6C-1	0.0005	<0.0005	<0.0005	<0.0005	<0.0005	0.0011	<0.0005	<0.0005	0.15
WW-7B-1	0.0068	<0.0005	0.0080	<0.0005	<0.0005	<0.0002	<0.0005	<0.0005	ND
WW-7C-1	0.0019	<0.0005	0.0012	0.0013	<0.0005	0.0022	<0.0005	<0.0005	ND
WW82-307-2-1	0.0006	<0.0005	<0.0005	<0.0005	<0.0005	0.0007	<0.0005	<0.0005	0.33
WW82-308-2-1	0.0040	0.0009	0.0260	0.0030	<0.0005	0.0100	<0.0005	<0.0005	0.18
WW82-314-3-1	0.0140	<0.0005	0.0020	0.0005	<0.0005	<0.0002	<0.0005	<0.0005	0.16
Mean	0.0042	0.0009	0.0108	0.0013	NA[a]	0.0018	NA	NA	0.24
Standard Deviation	0.0047	0.0000	0.0167	0.0009	NA	0.0031	NA	NA	0.22
N[a]	13	5	10	10	0	9	0	0	10

[a] Symbol: NA = not applicable; ND = no data available; N = number of samples detected.

Table 24. Summary of trace element analyses, Lake Wabamun.

Highvale Mine

	Mean	SD	Range	Number Analysed	Number Detected	Number Exceeding Recommended Limit
As	0.0074	0.0077	0.0018 to 0.315	21	21	2
B	0.16	0.24	0.08 to 4.00	19	19	1
Cd	0.0009	0.0004	<0.0005 to 0.0016	21	5	0
Co	0.0066	0.0104	<0.0005 to 0.0400	21	14	0
Cu	0.0191	0.0200	<0.0005 to 0.0800	21	20	0
Hg	NA	NA	NA	21	0	0
Pb	0.0024	0.0036	<0.0002 to 0.0115	21	12	0
Sb	0.0035	NA	<0.0005 to 0.0035	21	1	1
Se	0.165	NA	<0.0005 to 0.165	21	1	1

Highvale Overburden

	Mean	SD	Range	Number Analysed	Number Detected	Number Exceeding Recommended Limit
As	0.0047	0.0045	0.0004 to 0.012	17	16	0
B	NA	NA	0.63	1	1	0
Cd	NA	NA	NA	17	0	0
Co	0.0019	0.0011	<0.0005 to 0.004	17	13	0
Cu	0.0042	0.0040	0.0005 to 0.0145	17	17	0
Hg	NA	NA	NA	17	0	0
Pb	0.0016	0.0009	<0.0002 to 0.004	17	14	0
Sb	NA	NA	NA	17	0	0
Se	NA	NA	NA	17	0	0

Whitewood

	Mean	SD	Range	Number Analysed	Number Detected	Number Exceeding Recommended Limit
As	0.0042	0.0047	0.0005 to 0.014	13	13	0
B	0.243	0.222	0.120 to 0.850	10	10	0
Cd	0.0009	0.0	<0.0005 to 0.0009	13	5	0
Co	0.0108	0.0167	<0.0005 to 0.053	13	10	1
Cu	0.0013	0.0009	<0.0005 to 0.0025	13	10	0
Hg	NA	NA	NA	13	0	0
Pb	0.0018	0.0031	<0.0002 to 0.0100	13	9	0
Sb	NA	NA	NA	13	0	0
Se	NA	NA	NA	13	0	0

Arsenic was detected in all groundwater samples from both Highvale and Whitewood Mines spoil, and in all overburden sandstone samples at Highvale Mine. None of the samples from Whitewood Mine spoil or overburden sandstone exceeded the recommended limit for drinking water for arsenic of 0.050 mg/L. Two samples from Highvale Mine spoil exceeded the limit at values of 0.315 and 0.190 mg/L. The arsenic concentration in the spoil groundwater at Highvale Mine is approximately twice that of the premining overburden sandstone. Arsenic concentrations at Whitewood Mine ranged from 0.0005 to 0.014 mg/L, with a mean value of 0.0042 mg/L and standard deviation of 0.0047.

Boron was detected in all analysed Highvale and Whitewood spoil groundwater samples. The recommended concentration limit of boron for drinking water (1.0 mg/L) was not exceeded by any of the samples from either Whitewood spoil groundwater, or Highvale overburden sandstone. One sample from Highvale Mine spoil exceeded the recommended limit at a value of 4.0 mg/L. At Highvale Mine, boron concentrations ranged generally from 0.08 to 0.70 mg/L; one sample at 4.0 mg/L was obtained from a well (HV9-1) installed adjacent to an ash disposal area. The mean concentration of boron was 0.16 mg/L with a standard deviation of 0.24. Only one Highvale overburden sandstone groundwater sample was analysed for boron, and registered a concentration of 0.63 mg/L. It is not reasonable, however, to base a comparison of premining and spoil groundwater concentrations based only on this single determination.

Cadmium was detected in 24% of the groundwater samples from Highvale Mine spoil, and 38% of the samples from Whitewood Mine at a detection limit of 0.5 ppb. Cadmium was not detected in any of the Highvale overburden sandstone samples. The groundwater from Highvale and Whitewood spoil in all cases had levels of cadmium that were well below the recommended limit for drinking water of 0.005 mg/L. At Whitewood Mine, cadmium concentrations in five spoil groundwater samples were 0.0009 mg/L, with the remaining eight samples below detection.

Cobalt was detected in 65% of Highvale spoil groundwater samples, 76% of the Highvale overburden sandstone groundwater samples, and 77% of the Whitewood spoil groundwater samples at a detection limit of 0.0005 mg/L. The recommended limit for drinking water for cobalt of 0.050 mg/L was not exceeded by any samples from either Highvale spoil or overburden. Cobalt concentrations in the spoil groundwater at Highvale Mine are approximately twice the level of those from the unmined overburden. One sample from Whitewood Mine spoil exceeded the recommended limit at a value of 0.053 mg/L.

Copper was detected in 95% of Highvale spoil groundwater samples, 100% of the Highvale overburden sandstone groundwater samples, and 77% of Whitewood spoil groundwater samples at a detection limit of 0.0005 mg/L. The levels of copper detected in all Highvale and Whitewood groundwater samples were well within the recommended limit of 1.0 mg/L for drinking water. Despite more widespread occurrence in the unmined overburden, copper concentrations in the spoil are approximately 5 times higher than those in the overburden sandstone.

Mercury was not detected in any of the groundwater samples from either Highvale or Whitewood Mines spoil, or from the overburden sandstone at Highvale Mine, at a detection limit of 0.0005 mg/L.

Lead was detected in 57% of Highvale spoil, 82% of the Highvale overburden sandstone, and 69% of Whitewood spoil groundwater samples at a detection limit of 0.0005 mg/L. The recommended limit for drinking water for lead of 0.050 mg/L was not exceeded in any of the Highvale or Whitewood spoil groundwater samples. Detectable lead concentrations in the spoil groundwater are approximately twice as high as in the overburden sandstone at Highvale Mine. Levels of lead in Whitewood spoil groundwater ranged from less than 0.0002 to 0.0022 mg/L, with a mean concentration of 0.0018 mg/L and standard deviation of 0.0031.

Selenium was not detected in any of the spoil or premining groundwater samples at a detection limit of 0.0005 mg/L, with one exception. The exception, well HV9-1 in the spoil at Highvale Mine, registered a selenium concentration of 0.165 mg/L. This well is installed adjacent to an ash disposal area and has groundwater with ash-influenced characteristics.

Iron at a detection limit of 0.01 mg/L was detected in 100% of samples from Highvale spoil, Whitewood spoil, and from the Highvale overburden sandstone (Tables 25, 26, and 27). The acceptable level for iron for drinking water purposes of 0.3 mg/L was exceeded by 15% of samples from Highvale spoil, 69% of samples from Whitewood spoil, and 6% of samples from the Highvale overburden sandstone. The concentration of iron in the Highvale overburden sandstone ranged from 0.02 to 0.38 mg/L with a mean value of 0.08 mg/L and a standard deviation of 0.10. Iron values in the Highvale spoil water ranged from 0.03 to 7.92 mg/L, had a mean value of 0.60 mg/L, and a standard deviation of 1.76. This indicates that the concentration of iron in the Highvale spoil groundwater is over seven times that of the Highvale overburden sandstone, and is much more variable. The concentration of iron in Whitewood spoil water samples ranged from 0.04 to 6.36 mg/L, with a mean concentration of 1.70 mg/L, and a standard deviation of 1.75.

Sulfide, at a detection limit of 0.001 mg/L, was detected in 82% of samples from the Highvale overburden sandstone, 86% of samples from Highvale spoil, and 46% of samples from the Whitewood spoil (Tables 25, 26, and 27). The acceptable level of 0.3 mg/L sulfide for public drinking water was not exceeded by any samples from the Highvale overburden sandstone, or Highvale Mine spoil, or Whitewood Mine spoil. The concentration of sulfide in Highvale Mine spoil ranged from less than 0.001 to 0.080 mg/L, with a mean concentration of 0.010 mg/L, and a standard deviation of 0.017. The concentration of sulfide in Highvale overburden sandstone ranged from less than 0.001 to 0.040 mg/L, with a mean value of 0.014 mg/L, and a standard deviation of 0.014. A comparison of sulfide data from the Highvale overburden sandstone and the Highvale spoil groundwater indicates that the sulfide concentration of the Highvale overburden sandstone is almost one and one-half times that of the Highvale

Table 25. Highvale Mine spoil - iron and sulfide analyses (all values in mg/L).

Sample ID	Fe	S	Sample ID	Fe	S
Recommended Limit				0.30	0.300
Detection Limit				0.01	0.001
HV6-1-1	0.29	0.000	HV2-1-1	0.03	0.005
HV6-2-1	0.03	0.006	HV2-2-1	0.05	0.019
HV6-3-1	0.08	0.012	HV7-1-1	0.16	0.080
HV11-1-1	0.04	0.000	HV7-2-1	0.23	0.001
HV11-3-1	0.13	0.000	HV3-1-1	0.03	0.001
HV11-2-1	0.06	0.015	HV8-2-1	0.11	0.017
HV12-1-1	0.06	0.010	HV8-3-1	7.92	0.012
HV9-1-1	0.20	0.003	HV8-4-1	0.97	0.009
HV10-1-1	0.04	0.002	HV14-1-1	0.03	0.005
HV10-3-1	1.53	0.001	HV14-2-1	ND[a]	0.005
HV4-1-1	0.04	0.016			
Mean				0.60	0.010
Standard Deviation				1.76	0.017

[a] ND: No data available.

Table 26. Highvale overburden sandstone - iron and sulfide analyses (all values in mg/L).

Sample ID	Fe	S	Sample ID	Fe	S
Recommended Limit				0.30	0.300
Detection Limit				0.01	0.001
HE77-4-1-1	0.03	0.000	HV17-4-1	0.07	0.017
SB81-2-3-1	0.02	0.021	HV16-3-1	0.05	0.010
SB81-1-2-1	0.02	0.022	HV16-1-1	0.03	0.002
KE78-11-1-1	0.03	0.004	HV16-2-1	0.04	0.009
KE78-11-2-1	0.03	0.017	HV22-1-1	0.06	0.009
KE78-11-3-1	0.28	0.040			
HE77-3-1-1	0.05	0.000	HV19-2-1	0.03	0.001
HV23-5-1	0.14	0.039	HV24-6-1	0.07	0.000
HV21-1-1	0.08	0.002	HV24-5-1	0.38	0.040
Mean				0.08	0.014
Standard Deviation				0.10	0.014

Table 27. Whitewood Mine spoil - iron and sulfide analyses (all values in mg/L).

Sample ID	Fe	S	Sample ID	Fe	S
Recommended Limit				0.30	0.300
Detection Limit				0.01	0.001
WW4A-1	1.19	0.000	WW6A-1	6.36	0.003
WW4-1-1	2.46	0.000	WW7C-1	0.83	0.014
WW4B-1	2.80	0.004	WW82-307-2-1	0.06	0.000
WW4C-1	3.00	0.002	WW6C-1	0.26	0.000
WW82-308-2-1	0.04	0.017	WW7B-1	2.42	0.000
WW5C-1	1.40	0.000	WW82-314-3-1	0.22	0.003
WW2A-1	1.12	0.000			
Mean				1.70	0.003
Standard Deviation				1.75	0.006

spoil. The concentration of sulfide in the Whitewood Mine ranged from less than 0.001 to 0.017 mg/L, with a mean concentration of 0.003 mg/L and a standard deviation of 0.006.

6.3 INTERSITE COMPARISONS

The trace element analyses from spoil groundwater at the Battle River and Highvale sites have a log-normal distribution. In comparing the trace elements content in the four mine sites, essentially no statistically significant differences were found. Only boron and cadmium were significantly different at the 90% level. The boron content of groundwater in spoil at Highvale Mine is significantly lower than all three other mine sites. Only one boron analysis is available from the overburden sandstone at Highvale and it is not significantly different from the spoil. The boron content of groundwater at Diplomat Mine is significantly greater than that at Vesta Mine. Neither Diplomat nor Vesta Mines contain significantly more boron than the Battle River Bed.

No other statistically significant differences were identified between trace element content of spoil groundwater or between spoil groundwater and groundwater in premining aquifers.

7. SUMMARY

1. Major ion chemistry of spoil groundwater at all four mines studied is characterized by increased salinity and changed composition relative to premining aquifers. Salinity increases ranged from 2.4 to 5.9 times the premining levels. Sodium and sulfate account for the major increase in most areas, although calcium and magnesium are significantly increased at Diplomat and Vesta Mines in the Battle River mining area.
2. Major ion chemistry in spoil at Diplomat and Vesta Mines is fundamentally similar with only sodium and sulfate concentrations being significantly higher at Vesta Mine.
3. Major ion chemistry in groundwater in spoil at Diplomat and Vesta Mines at the Battle River mining area is characterized by significantly higher total salinity and significantly greater concentrations of most ionic constituents relative to groundwater in spoil at Highvale and Whitewood Mines at the Lake Wabamun mining area.
4. It is not known whether differences in major ion chemistry between the Battle River and Lake Wabamun mining areas reflect solely geological differences between the overburden in the two areas or whether climatically controlled hydrologic factors are also important.
5. Seasonal fluctuations in water chemistry display a generally consistent pattern at the Battle River mining area. Salinity in both water-table wells and at the base of the spoil is the lowest in April, increases to a maximum during the summer and fall and, in most wells, decreases in December or January. The maximum salinity is generally from 7 to 25% higher

than the minimum. In addition to this pattern, some water-table wells display significant decreases in salinity related to recharge from individual large rainstorms.

6. No clear pattern of chemical fluctuations has emerged from wells at Highvale Mine.
7. The cause of much of the seasonal variation in spoil-water chemistry is not understood.
8. No clear pattern is yet evident in long-term trends in water chemistry. Some wells display a progressive decrease in salinity over the four-year record of observation, whereas others have remained essentially constant.
9. In the Battle River mining area, arsenic, boron, cobalt, copper, and lead were widely detected in groundwater samples from spoil at Diplomat and Vesta Mines, as well as from the unmined Battle River Bed aquifer, however, the recommended concentration limit was rarely exceeded. Mercury was not detected in any of the groundwater samples from the Battle River mining area. Selenium and antimony were only rarely detected. Cadmium was widely detected in samples from both the Battle River Bed and Vesta Mine spoil. Six out of 14 samples from Diplomat Mine exceeded the crop application limit for boron. The recommended limits for cobalt and boron were each exceeded once in samples from Vesta Mine. One sample from the Battle River Bed exceeded the recommended limit for antimony.

In the Lake Wabamun mining area, arsenic, boron, cobalt, copper, and lead were widely detected in groundwater samples from the spoil of Pit 01 of Highvale Mine, the unmined overburden at Highvale Mine, and the spoil at Whitewood Mine, but the recommended concentration limits were rarely exceeded.

Mercury was not detected in any of the groundwater samples from the Lake Wabamun mining area. Selenium and antimony were rarely detected. Cadmium was detected in one-half of the samples from Whitewood Mine and one-quarter of the samples from Highvale Mine, but not detected in samples from the unmined overburden. In samples from Pit 01 of Highvale Mine, only one groundwater sample from the spoil exceeded the recommended limit for arsenic. One sample from an ash disposal area exceeded the recommended limit for arsenic, selenium, and antimony. None of the samples from the unmined overburden exceeded any of the recommended maximum concentrations. One sample out of 10 analysed from Whitewood exceeded the recommended limit for cobalt.

8. REFERENCES CITED

Alberta Environment. 1980. Hydrogeologic effects of coal strip mining at Whitewood Mine, Alberta. Groundwater Branch, Earth Sciences Division, Environmental Protection Services, Alberta Environment. Edmonton, Alberta. January 1980.

Maslowski Schutze, A. 1986. Chemical and mineralogical properties of overburden at the Battle River study area, east-central Alberta. Alberta Land Conservation and Reclamation Council Report #RRTAC 86-5. 50 pp. and Appendices.

Maslowski Schutze, A. In press. Geology of the Highvale study site: Plains Hydrology and Reclamation Project. Alberta Land Conservation and Reclamation Council Report.

Maslowski Schutze, A., R. Li, M.M. Fenton, and S.R. Moran. 1986. Geology of the Battle River study site: Plains Hydrology and Reclamation Project. Alberta Land Conservation and Reclamation Council Report #RRTAC 86-4. p. 70.

McNeely, R.N., V.P. Neimanis, and L. Dwyer. 1979. Water quality source book. Environment Canada Inland Waters Directorate, Water Quality Branch, Ottawa, 1979. Supplies and Services Canada, Catalogue Number EN37-54/1979.

Montreal Engineering. 1978. Highvale Mine environmental hydrogeology study. Consultant's Report for TransAlta Utilities Ltd., Calgary, Alberta.

Montreal Engineering. 1979. Whitewood Mine - 1979 environmental hydrogeology study. Consultant's Report for TransAlta Utilities Ltd., Calgary, Alberta.

Trudell, M.R. 1986. Post-mining water supply potential of the Highvale Mine site. Alberta Land Conservation and Reclamation Council Report #RRTAC 86-7. 25 pp.

Trudell, M.R., G.J. Sterenberg, and S.R. Moran. 1986. Post-mining groundwater supply at the Battle River site east-central Alberta. Alberta Land Conservation and Reclamation Council Report #RRTAC 86-6. 49 pp.

Trudell, M.R., A. Maslowski, E. Wallick, and S.R. Moran. 1983. Prediction of groundwater chemistry in reclaimed landscapes. In Proceedings, Second Annual Alberta Reclamation Conference, February 23-24, 1983. Alberta Chapter, Canadian Land Reclamation Association. pp. 238-251.

Report 2:

IMPACTS OF SURFACE MINING ON CHEMICAL QUALITY OF STREAMS IN THE BATTLE RIVER MINING AREA

BY

MARK R. TRUDELL

Terrain Sciences Department
Alberta Research Council

Prepared For

The Plains Coal Reclamation Research Program

of

THE LAND CONSERVATION AND RECLAMATION COUNCIL

(Reclamation Research Technical Advisory Committee)

1988

TABLE OF CONTENTS

Page

LIST OF TABLES 110

LIST OF FIGURES 111

ABSTRACT 112

1. INTRODUCTION 113

2. CHARACTERIZATION OF SURFACE WATER AT THE BATTLE RIVER SITE 114

3. CONTAMINATION OF SURFACE WATER BY SPOIL GROUNDWATER DISCHARGE AT THE BATTLE RIVER SITE 126

4. CONCLUSIONS 134

5. REFERENCES CITED 135

LIST OF TABLES

Page

1. Chemical Analyses of Water Samples from the Battle River, 1980-1982 116
2. Chemical Analyses of Water Samples from Paintearth Creek, 1980-1982 119
3. Chemical Analyses of Water Samples from Big Knife Creek 123
4. Chemical Analyses of Water Samples from Tributaries of Paintearth Creek 124
5. Chemical Analyses of Water from Springs 130

LIST OF FIGURES

Page

1. Location of Staff Gauge Sites in the Battle River Study Area, Except for SG-12, Which is Located on the Battle River at SE22-40-14-W4 115

2. Chemical Hydrograph of Total Dissolved Solids for the Battle River 117

3. Piper Trilinear Diagram of Water Composition for the Battle River 118

4. Chemical Hydrograph of Total Dissolved Solids for Paintearth Creek, 1980-1982 120

5. Piper Trilinear Diagram of Water Composition for Paintearth Creek 121

6. Generalized Stratigraphic Column for the Battle River Study Area 127

7. Location of Springs in the Battle River Study Area. SP81-1 is Located at SW32-39-15-W4 129

8. Piper Trilinear Diagram for Spring Water Samples, Battle River Site 131

ABSTRACT

This report describes the chemical quality of water in streams in the Battle River mining area, and the potential impact of groundwater discharge from surface mines. Except for the Battle River, streams in the study area generally flow only during spring melt and after heavy summer rains. The Battle River flows year-round, and numerous springs along the valley walls are discharging to the Battle River. Twenty-five springs have been mapped along the Battle River valley, and based on water quality characteristics the discharge from 12 springs shows evidence of spoil groundwater origin. However, the salt load to the Battle River from this spring discharge is not significant in terms of water quality in the river. There are no springs of significant size in the valley of Paintearth Creek.

1. INTRODUCTION

This report deals with two distinct components of the relationship between surface water, primarily streams, and surface mining at the Battle River site. More specifically, it investigates the potential for the quality of stream water in the Battle River area to be degraded as a result of mining.

The first section of this report is a characterization of existing surface water quality, including comparisons between gauging stations upstream and downstream from the mining sites. This section establishes a baseline against which changes in water quality as a result of mining may be monitored.

The second section is an evaluation of the potential for streams in the Battle River area to be affected by groundwater discharge from spoil areas. This discharge, in the form of springs, is quantitatively integrated (in terms of flow rates and water quality) to establish the effects of mining on the quality of water in the Battle River.

2. CHARACTERIZATION OF SURFACE WATER AT THE BATTLE RIVER SITE

Periodic sampling of streams in the Battle River area was carried out between 1980 and 1982. Samples were collected from each of the 10 staff gauge sites illustrated in Figure 1. Two sites were situated on the Battle River (SG-3 and SG-12), three on Paintearth Creek (SG-5, SG-7, SG-10), one on a tributary of the Battle River (SG-4 on Big Knife Creek), and four on tributaries of Paintearth Creek (SG-1, SG-2, SG-8, and SG-9).

Flow in all streams except the Battle River occurs almost exclusively during spring melt. By early May surface flow generally ceases and the water present in stream channels is stagnant. Only the heaviest summer rainfall events result in runoff and stream flow, and such occurrences are generally of short duration - one or two days. Flow occurs year-round in the Battle River, as measured at staff gauge 12. No discharge measurements were done at staff gauge 3 because it is in the backwater of the power plant reservoir.

The chemical analyses of water samples from the Battle River are listed in Table 1, and a chemical hydrograph of total dissolved solids (TDS) is shown in Figure 2. The water in the Battle River is a Ca^{2+}, Mg^{2+}, Na^{+} - HCO_3^{-}, SO_4^{2-} type water (Figure 3) with TDS ranging from 250 to 500 mg/L. There is a tendency for TDS to increase through the year, with minimum concentrations occurring in the spring and maximums in the fall. In general, the water quality at the two staff gauge sites is virtually the same; there is no tendency for the downstream site (SG-12) to be of lower quality than SG-3, located near the centre of the study area.

Chemical analyses and a chemical hydrograph of TDS for Paintearth Creek are presented in Table 2 and Figure 4, respectively. The quality of water in Paintearth Creek is highly variable, but in general terms is of Na^{+}, Ca^{2+}, Mg^{2+} - HCO_3^{-}, SO_4^{2-} type (Figure 5) with TDS ranging from 150 to 650 mg/L. As in the Battle River, there is a tendency for the lowest TDS concentrations to occur in the spring, increasing to maximum concentrations in the fall. The upstream site (SG-5) has the poorest water quality, while in 8 of 11

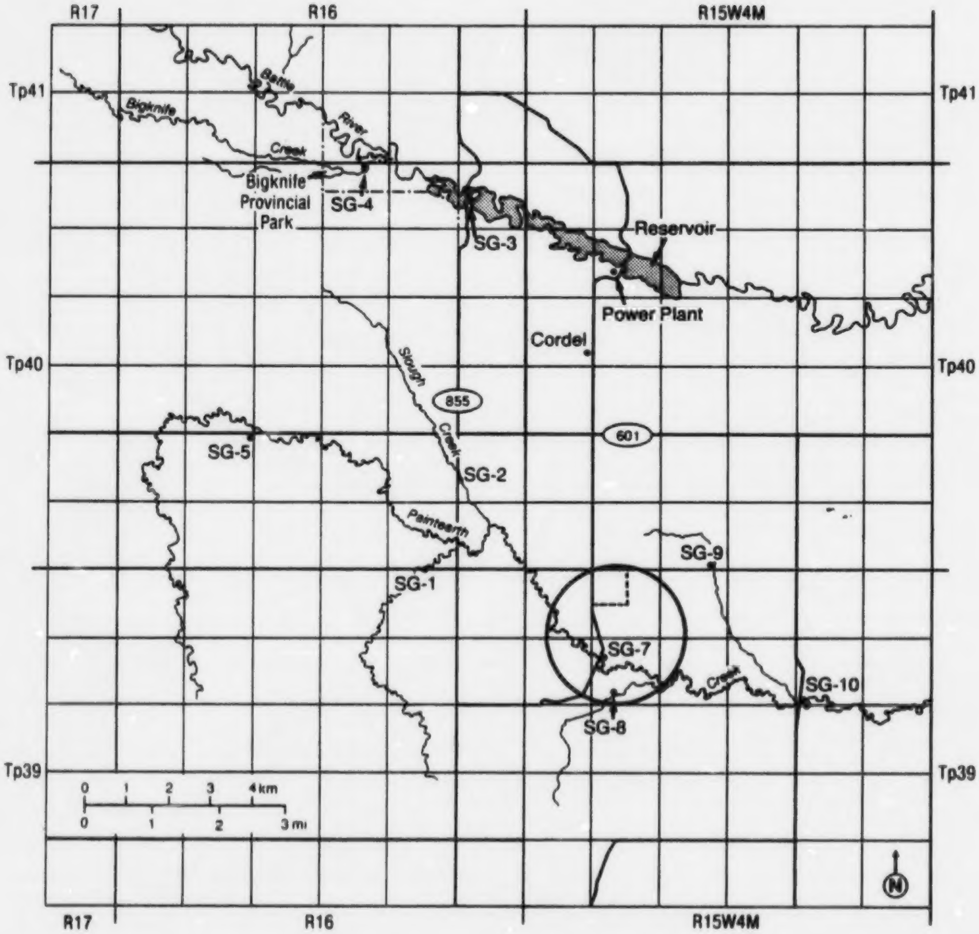

R17
R16
R15W4M
Tp41
Tp40
Tp39
Battle River
Bigknife Creek
Bigknife Provincial Park
SG-4
SG-3
Reservoir
Power Plant
Cordel
Sounding Creek
855
601
SG-5
SG-2
Paintearth
SG-1
SG-9
SG-7
Creek
SG-10
SG-8
0 1 2 3 4 km
0 1 2 3 mi
N

Figure 1. Location of staff gauge sites in the Battle River study area, except for SG-12, which is located on the Battle River at SE22-40-14-W4.

Table 1. Chemical analyses of water samples from the Battle River, 1980-1982.
All concentrations reported in mg/L; DO - dissolved oxygen.

Stream: Battle River

Site No.	Date	TDS	Ca^{2+}	Mg^{2+}	Na^+	K^+	CO_3^{2-}	HCO_3^-	SO_4^{2-}	Cl^-	NO_3^-	DO	pH
SG-3	17/07/80	371	29.0	12.0	49.0	8.3	0.0	189.0	65.0	11.0	1.3	6.0	8.30
	24/09/80	391	34.0	14.0	42.0	7.6	0.0	244.0	36.0	14.0	1.1	11.6	8.18
	24/04/81	387	40.7	12.8	40.0	11.7	0.0	225.0	43.5	12.0	0.4	7.0	7.85
	27/05/81	439	44.3	14.6	43.8	8.8	4.6	241.0	70.0	9.0	0.3	4.5	8.49
	09/07/81	446	52.0	17.7	55.0	9.2	0.0	257.0	42.5	11.0	0.3	7.5	8.51
	11/08/81	480	32.2	16.5	66.0	10.8	4.1	261.0	70.0	14.4	0.4	6.6	8.64
	17/09/81	405	46.1	17.0	30.0	5.4	0.0	265.0	27.3	2.0	1.9	7.9	8.14
	22/10/81	449	52.0	18.0	41.2	8.3	0.0	274.0	43.2	5.2	1.2	12.0	8.19
	05/05/82	275	29.4	10.0	25.0	8.8	0.0	124.0	55.0	6.8	7.0	9.8	7.35
	02/06/82	408	49.5	15.0	38.0	11.2	0.0	221.0	62.0	7.0	2.5	9.2	7.62
	01/07/82	459	48.3	17.5	55.0	10.6	12.2	232.0	73.0	7.4	1.5	11.8	8.44
	04/08/82	376	39.8	13.4	34.1	8.8	0.0	212.0	56.0	1.4	1.2	7.0	8.19
	02/09/82	428	48.6	16.1	36.0	8.5	0.0	244.0	60.0	3.6	0.9	7.2	8.09
	06/10/82	479	54.0	18.1	44.0	8.7	0.0	270.0	68.0	0.5	2.5	8.5	7.96
SG-12	27/05/80	420	42.0	13.8	53.0	10.4	0.0	221.0	63.0	13.0	1.1	8.5	8.06
	17/07/80	390	24.0	11.0	65.0	7.1	0.0	191.0	35.0	46.0	3.8	6.2	8.16
	18/09/80	438	33.0	14.0	56.0	7.6	0.0	260.0	50.0	12.0	0.4	9.5	7.86
	23/04/81	401	41.4	13.3	42.5	11.7	0.0	230.0	47.0	14.0	0.4	8.4	8.08
	22/05/81	449	44.2	14.3	46.3	9.6	0.0	251.0	72.0	8.0	0.7	8.0	8.22
	09/07/81	442	36.8	15.9	55.0	9.2	7.2	232.0	77.0	8.0	0.2	10.1	8.77
	13/08/81	480	33.2	16.5	68.0	11.3	9.2	253.0	70.0	15.0	0.3	7.3	8.43
	15/09/81	394	42.3	16.8	33.8	5.0	4.5	238.0	28.6	4.0	1.7	8.3	8.34
	20/10/81	435	50.1	17.6	41.2	8.3	6.9	262.0	36.6	5.4	0.8	11.6	8.30
	05/05/82	330	33.0	12.1	35.0	8.8	0.0	156.0	62.0	6.6	7.0	10.4	7.55
	07/06/82	394	47.1	14.2	36.7	11.6	2.6	209.0	62.0	8.2	0.4	9.6	7.85
	08/07/82	329	22.8	7.2	50.0	5.2	0.0	ND	57.0	0.0	165.0	7.5	7.69
	05/08/82	372	40.0	13.5	32.6	8.5	0.0	214.0	50.0	1.4	1.9	8.4	7.89
	02/09/82	424	48.1	16.0	36.0	8.8	1.0	248.0	54.0	0.0	1.2	7.7	8.09
	13/10/82	474	56.0	18.4	47.3	8.2	7.2	256.0	69.0	5.0	1.1	9.7	8.21

ND - no data.

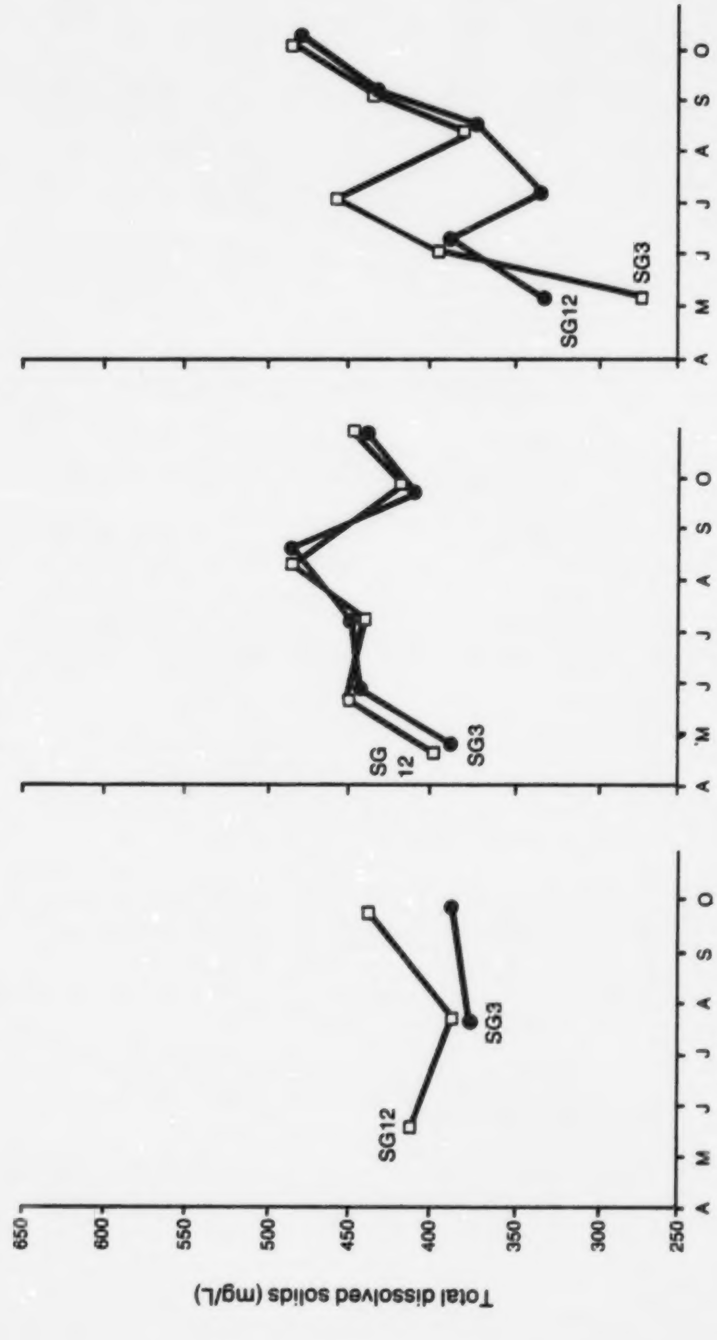


Figure 2. Chemical hydrograph of total dissolved solids for the Battle River.

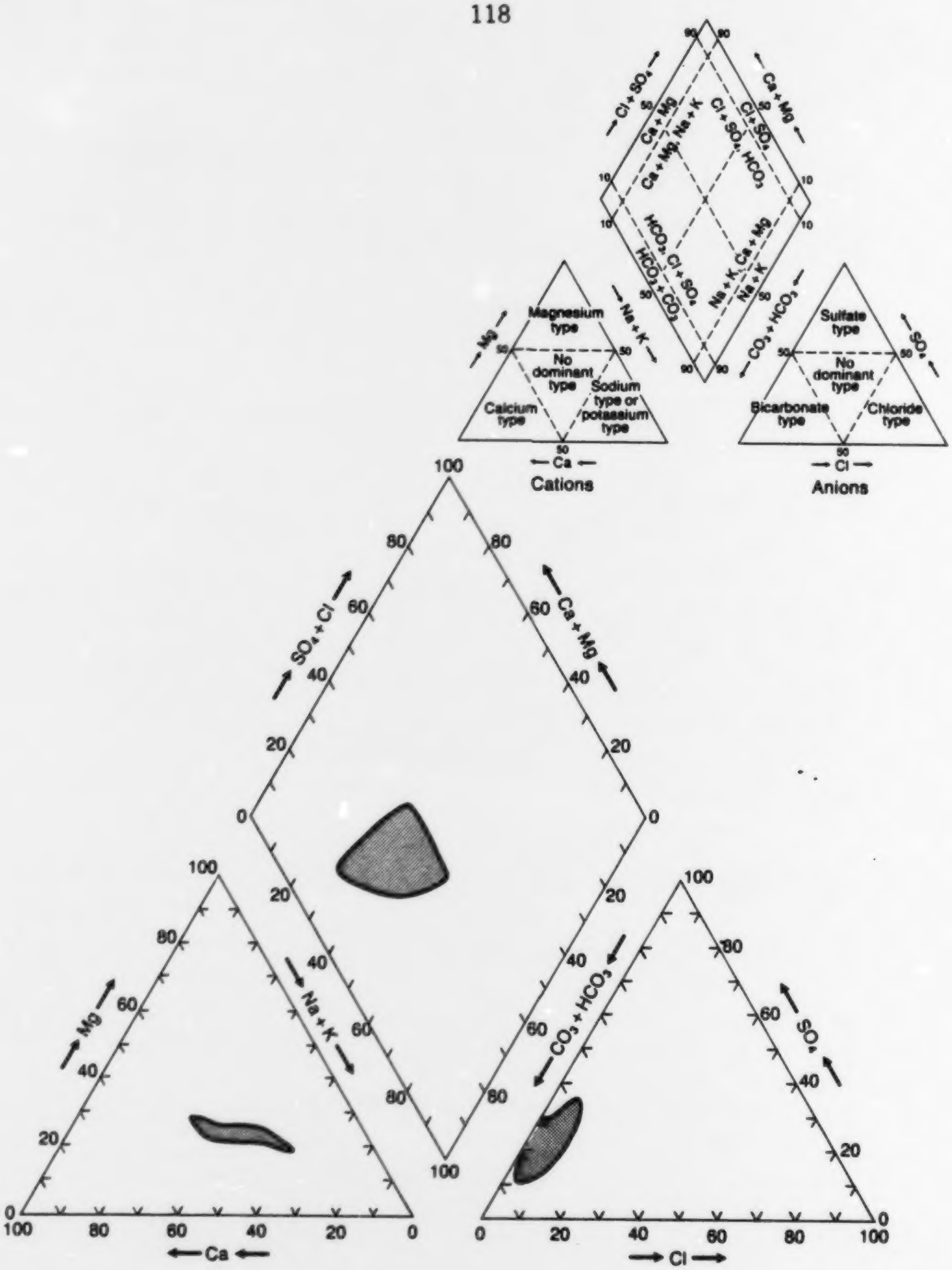


Figure 3. Piper trilinear diagram of water composition for the Battle River.
The patches shown represent the overall distribution of water composition from three gauging stations on the Battle River.

Table 2. Chemical analyses of water samples from the Paintearth Creek, 1980-1982. All concentrations reported in mg/L; DO - dissolved oxygen.

Stream: Paintearth Creek

Site No.	Date	TDS	Ca^{2+}	Mg^{2+}	Na^+	K^+	CO_3^{2-}	HCO_3^-	SO_4^{2-}	Cl^-	NO_3^-	DO	pH
SG-5	17/07/80	264	18.0	4.3	47.0	5.9	0.0	170.0	5.0	6.0	1.3	3.2	7.45
	18/09/80	378	25.0	7.3	64.0	5.6	0.0	270.0	5.0	2.0	0.4	7.6	7.51
	22/04/81	278	13.7	3.3	60.0	5.4	0.0	149.0	38.5	6.0	0.6	10.5	8.03
	22/05/81	449	23.3	5.6	94.0	6.3	0.0	257.0	60.0	1.0	0.4	4.6	7.87
	09/07/81	622	25.8	7.1	113.0	6.6	0.0	366.0	43.8	0.0	0.4	ND	8.57
	29/04/82	215	12.8	3.4	39.0	6.0	0.0	78.0	61.0	0.8	0.7	11.8	7.22
	27/05/82	356	26.1	6.2	65.0	6.4	0.0	160.0	85.0	0.4	0.9	8.8	7.63
	01/07/82	451	31.0	8.1	85.0	6.1	0.0	251.0	64.0	1.0	5.2	9.1	7.54
	04/08/82	332	21.2	5.4	51.0	7.3	0.0	212.0	15.0	0.0	5.6	10.2	7.77
	03/09/82	367	25.4	6.4	61.0	6.2	0.0	240.0	14.0	1.2	6.0	6.7	7.75
	13/10/82	418	30.1	7.2	74.0	5.5	0.0	274.0	22.0	2.0	1.0	12.0	7.74
SG-7	11/07/80	350	13.0	2.8	79.0	6.7	0.0	151.0	81.0	2.0	1.0	ND	7.81
	17/09/80	252	11.0	2.8	46.0	5.6	0.0	135.0	29.0	6.0	1.3	8.6	7.55
	22/05/81	221	10.8	2.6	41.3	6.5	0.0	92.0	60.0	2.0	0.6	7.8	7.47
	09/07/81	271	13.5	3.3	46.8	7.3	0.0	138.0	41.0	0.0	0.7	9.5	8.19
	11/08/81	238	9.3	2.1	42.0	5.4	0.0	98.0	47.0	3.0	2.1	ND	7.98
	16/09/81	224	13.0	3.0	40.0	2.9	0.0	120.0	25.4	0.0	0.9	7.8	7.89
	21/10/81	285	15.5	3.8	49.4	6.7	0.0	166.0	26.0	0.0	0.6	13.6	7.65
	30/04/82	172	7.4	2.1	33.8	5.5	0.0	57.0	52.0	0.8	2.4	11.0	6.92
	28/05/82	200	9.4	2.4	39.0	4.9	0.0	76.0	47.0	0.6	1.4	7.5	6.99
	01/07/82	336	18.3	4.8	54.0	6.3	0.0	111.0	42.0	0.0	85.0	9.2	7.13
	05/08/82	259	12.3	3.5	43.7	7.4	0.0	125.0	36.0	1.4	6.4	5.0	7.30
	03/09/82	247	9.6	2.6	45.1	6.9	0.0	113.0	33.0	0.0	4.6	4.9	7.46
	13/10/82	278	11.2	3.3	50.0	5.7	0.0	119.0	38.0	0.0	3.2	10.0	7.59
SG-10	16/07/80	211	11.0	2.8	39.0	5.1	0.0	106.0	23.0	6.0	1.3	3.25	7.43
	22/05/81	181	11.4	2.9	33.8	3.8	0.0	90.0	34.0	0.0	0.4	7.4	7.52
	09/07/81	293	17.6	4.5	45.6	6.9	0.0	164.0	38.0	0.0	0.4	7.2	7.72
	11/08/81	305	16.9	4.4	51.0	7.5	0.0	173.0	31.5	2.0	0.4	7.8	8.14
	15/09/81	364	24.7	6.2	51.2	4.6	0.0	248.0	9.4	2.0	0.5	5.9	7.82
	20/10181	645	54.0	13.9	95.0	8.3	0.0	415.0	37.1	6.0	0.4	10.5	7.76
	04/05/82	160	7.8	2.2	32.0	5.8	0.0	58.0	44.0	1.0	2.2	9.4	6.45
	02/06/82	257	13.3	3.6	45.0	5.6	0.0	105.0	54.0	1.0	1.2	10.0	7.53
	08/07/82	203	8.2	2.2	41.7	5.0	0.0	79.0	40.0	0.0	4.6	6.8	7.67
	05/08/82	293	16.0	4.1	48.2	6.1	0.0	140.0	42.0	0.0	6.2	8.0	7.52
	02/09/82	266	14.6	3.6	45.4	6.7	0.0	146.0	30.0	0.0	1.7	4.8	7.56
	13/10/82	335	12.7	4.4	54.0	6.6	0.0	128.0	46.0	0.0	5.8	8.8	7.50

ND - no data.

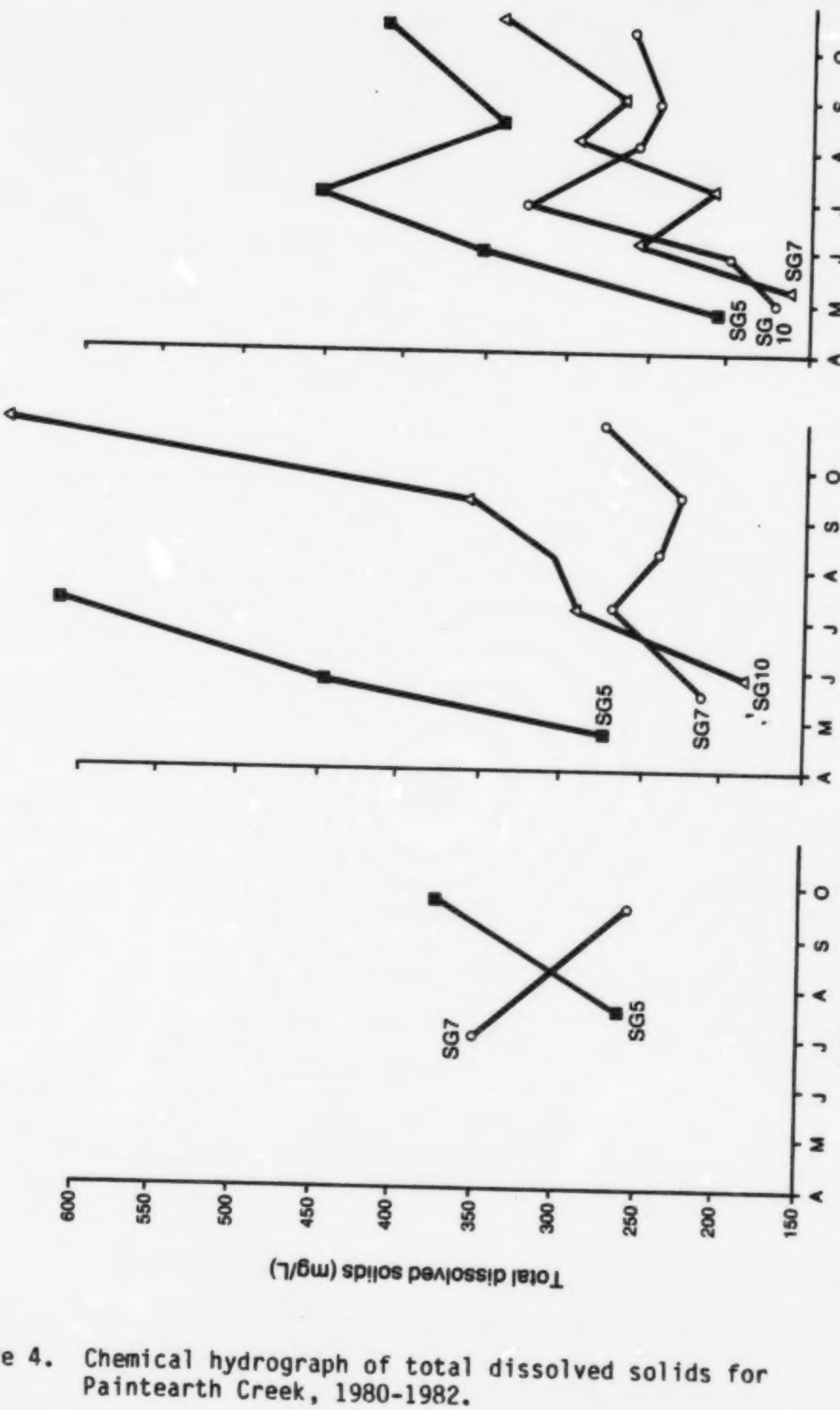


Figure 4. Chemical hydrograph of total dissolved solids for Paintearth Creek, 1980-1982.

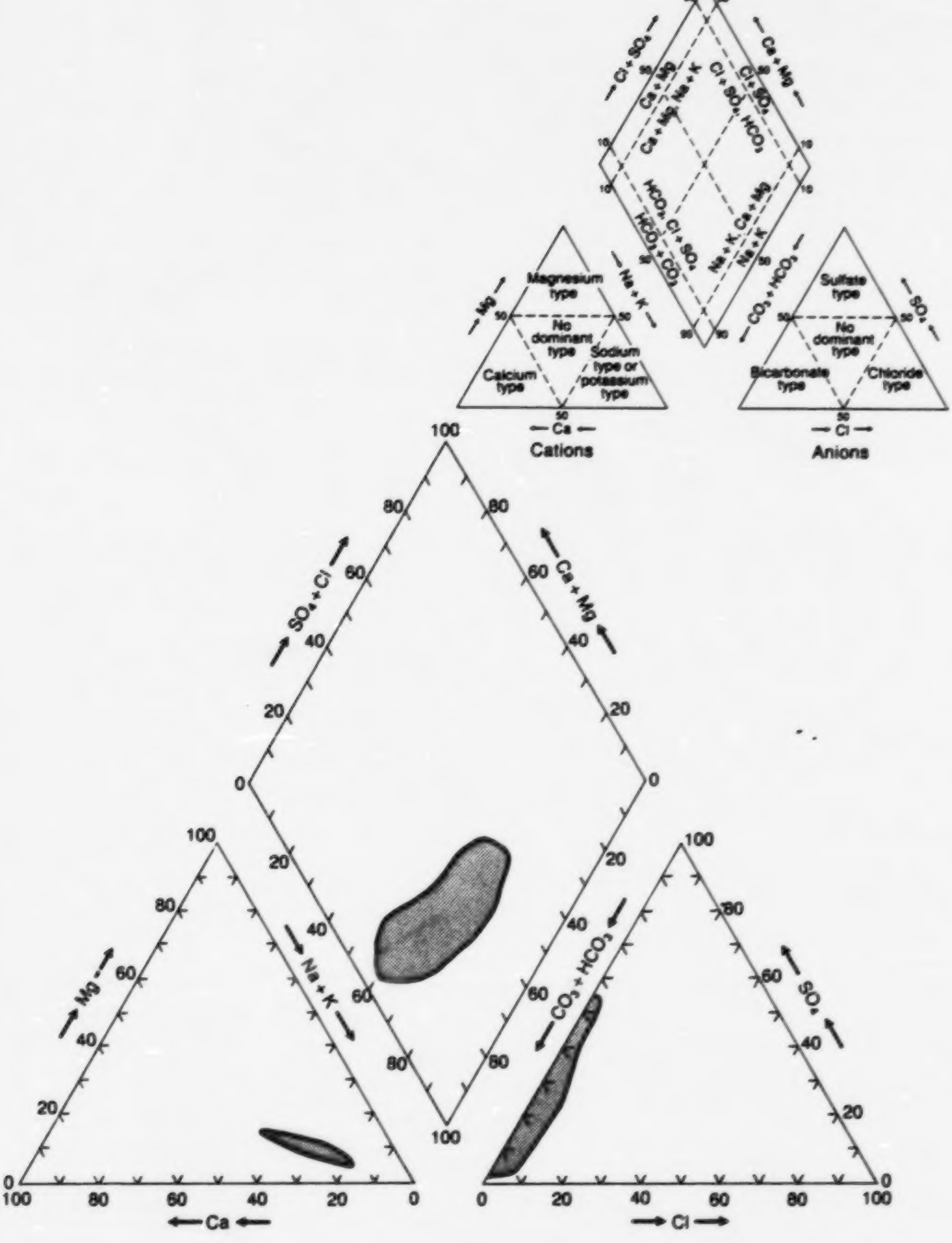


Figure 5. Piper trilinear diagram of water composition for Paintearth Creek.
The patches shown represent the overall distribution of water composition from two gauging stations on Paintearth Creek.

samplings the central site (SG-7) had better water quality than the downstream site (SG-10). The occurrence of poorer water at the upstream site is due to the fact that the channel of Paintearth Creek at site SG-5 is smaller, shallower, and more subject to the effects of evaporation than the downstream site.

The water quality in Big Knife Creek (SG-4), a tributary of the Battle River, is also quite variable, but usually of the Ca^{2+}, Mg^{2+}, Na^{+} or Na^{+}, Ca^{2+}, Mg^{2+} - HCO_3^{-}, SO_4^{2-} type. Total dissolved solids concentrations range from 250 to 700 mg/L, and are generally lowest during the spring. Table 3 lists the chemical analyses of water samples from this site.

The tributaries of Paintearth Creek have a wide variety of water quality characteristics. Two streams, at sites SG-2 (Slough Creek) and SG-9 dry up completely during the summer months, therefore the water quality often reflects the effects of evaporation. These streams typically have a greater sulfate component than Paintearth Creek, although otherwise the water chemical makeup is similar. The tributaries at sites SG-1 and SG-8 have water in the stream channels all summer, and have a water quality virtually the same as Paintearth Creek, but of slightly lower salinity, with TDS ranging from 150 to 450 mg/L. These streams have the lowest TDS concentrations in the fall. Table 4 is a listing of chemical analyses of all water samples from tributaries of Paintearth Creek.

Table 3. Chemical analyses of water samples from the Big Knife Creek, 1980-1982. All concentrations reported in mg/L; DO - dissolved oxygen.

Stream: Big Knife Creek

Site No.	Date	TDS	Ca^{2+}	Mg^{2+}	Na^+	K^+	CO_3^{2-}	HCO_3^-	SO_4^{2-}	Cl^-	NO_3^-	DO	pH
SG-4	28/05/80	568	53.0	11.9	79.0	9.2	0.0	354.0	38.0	13.0	0.4	5.3	7.78
	21/07/80	482	29.0	8.3	76.0	7.1	40.0	272.0	30.0	10.0	1.3	3.6	8.21
	24/09/80	550	42.0	12.0	80.0	7.7	4.0	378.0	10.0	16.0	0.4	3.8	7.80
	24/04/81	353	27.7	6.6	54.0	6.3	0.0	216.0	30.5	6.0	0.2	5.5	7.51
	27/05/81	498	47.1	12.3	65.0	7.5	0.0	316.0	40.5	5.0	0.2	6.6	7.86
	09/07/81	589	47.4	14.6	76.0	9.6	0.0	390.0	43.2	6.0	0.2	3.1	7.98
	13/08/81	498	33.0	13.7	81.0	11.3	21.6	308.0	18.0	9.2	0.3	3.0	8.29
	16/09/81	467	39.4	15.9	56.2	7.1	7.9	300.0	18.4	8.0	0.5	2.1	8.29
	21/10/81	510	45.3	16.4	64.0	10.8	0.0	344.0	13.6	9.0	0.4	2.6	7.69
	05/05/82	272	20.6	5.8	41.2	7.9	0.0	122.0	56.0	1.0	3.0	9.4	7.37
	02/06/82	411	47.5	13.9	40.0	11.3	0.0	235.0	53.0	6.8	0.4	6.2	7.25
	07/07/82	355	32.6	9.2	48.8	7.8	0.0	215.0	35.0	0.0	1.1	8.4	7.90
	06/08/82	390	39.7	13.0	36.7	9.0	0.0	230.0	45.0	2.8	3.4	5.4	7.83
	02/09/82	468	48.4	14.6	47.9	9.0	0.0	310.0	30.0	0.0	0.6	5.4	7.63
	13/10/82	654	64.0	16.8	84.0	9.4	0.0	441.0	17.0	11.0	1.6	3.6	7.47

Table 4. Chemical analyses of water samples from tributaries of the Paintearth Creek, 1980-1982. All concentrations reported in mg/L; DO - dissolved oxygen.

Stream: Paintearth Creek Tributaries

Site No.	Date	TDS	Ca^{2+}	Mg^{2+}	Na^+	K^+	CO_3^{2-}	HCO_3^-	SO_4^{2-}	Cl^-	NO_3^-	DO	pH
SG-1	23/05/80	246	15.1	2.8	50.0	7.5	0.0	118.4	41.2	1.0	2.3	5.6	7.85
	16/07/80	274	15.0	3.0	45.0	5.1	0.0	155.0	26.0	6.0	1.4	7.5	7.48
	17/09/80	275	15.0	3.3	45.0	6.0	0.0	158.0	20.0	6.0	1.4	6.4	7.54
	22/04/81	184	8.9	2.2	35.0	5.0	0.0	90.0	34.5	6.0	0.6	7.7	7.62
	26/05/81	250	16.4	3.7	42.5	4.2	0.0	145.0	29.5	1.0	0.4	2.4	7.60
	09/07/81	310	18.5	4.3	55.0	6.7	0.0	194.0	28.2	0.0	0.3	7.7	7.95
	12/08/81	318	18.9	4.6	57.0	7.9	5.1	203.0	11.7	3.0	0.3	9.2	8.48
	16/09/81	367	28.2	5.5	60.0	5.0	0.0	230.0	18.2	0.0	0.5	7.5	8.06
	21/10/81	436	33.1	7.2	75.0	7.9	0.0	282.0	23.5	0.8	0.4	13.6	8.01
	29/04/82	177	7.9	2.1	34.0	5.6	0.0	67.0	43.0	1.0	0.6	10.4	6.97
	27/05/82	247	13.5	3.2	47.2	5.9	0.0	109.0	51.0	0.6	1.0	7.8	7.39
	01/07/82	281	16.1	4.2	53.0	7.1	0.0	146.0	36.0	0.0	10.8	7.1	6.72
	04/08/82	240	11.6	3.0	38.5	5.7	0.0	126.0	20.0	0.0	9.8	6.8	7.56
	03/09/82	386	19.4	5.1	72.0	8.7	0.0	216.0	45.0	1.0	1.7	4.8	7.45
	06/10/82	382	13.7	4.8	52.0	7.0	0.0	148.0	41.0	2.0	3.6	8.3	7.32
SG-2	07/07/80	502	23.0	6.3	10.6	8.6	0.0	235.0	110.0	6.0	1.4	3.5	8.10
	17/09/80	384	17.0	4.8	83.0	5.6	0.0	175.0	90.0	9.0	0.4	6.2	7.50
	22/04/81	765	23.4	7.6	199.0	11.2	0.0	262.0	245.0	6.0	1.1	9.5	8.04
	26/05/81	402	15.2	3.7	38.8	5.0	0.0	302.0	29.0	0.0	0.4	0.7	7.50
	10/07/81	2027	101.0	26.1	473.0	20.8	0.0	398.0	1000.0	2.0	1.2	8.2	8.06
	29/04/82	493	18.5	5.7	115.0	7.1	0.0	150.0	172.0	1.0	1.5	12.0	7.83
	27/05/82	1242	58.0	16.2	283.0	8.8	0.0	218.0	638.0	6.2	3.8	10.2	7.55
	08/07/82	448	15.9	5.2	105.0	7.1	0.0	139.0	149.0	0.0	6.8	3.1	7.16
	03/09/82	446	18.1	5.5	96.0	6.2	0.0	226.0	81.0	0.0	3.4	2.4	7.63
	06/10/82	453	14.2	4.3	112.0	7.5	0.0	169.0	138.0	0.0	3.1	8.6	7.24

continued . . .

Table 4. Concluded.

Site No.	Date	TDS	Ca^{2+}	Mg^{2+}	Na^+	K^+	CO_3^{2-}	HCO_3^-	SO_4^{2-}	Cl^-	NO_3^-	DO	pH
SG-8	24/04/81	199	9.4	2.4	40.0	6.3	0.0	91.0	33.5	6.0	1.4	7.2	7.42
	21/05/81	309	18.1	6.2	51.0	6.3	0.0	140.0	70.0	1.0	0.9	7.5	7.86
	08/07/81	306	15.0	3.6	54.9	6.9	0.0	169.0	35.8	0.0	0.5	2.2	8.04
	11/08/81	360	13.0	3.5	75.0	6.7	0.0	167.0	56.0	2.8	1.4	0.6	8.27
	15/09/81	314	15.4	3.8	58.8	3.8	0.0	176.0	39.1	1.0	0.9	ND	7.90
	20/10/81	339	11.8	3.3	72.0	7.5	0.0	164.0	41.7	4.6	0.7	1.45	7.54
	30/04/82	212	8.2	2.5	34.9	5.8	0.0	72.0	50.0	3.0	1.2	10.8	7.27
	28/05/82	288	14.2	3.6	53.0	6.1	0.0	118.0	60.0	0.6	2.1	8.2	7.41
	08/07/82	410	10.7	5.0	66.0	6.1	0.0	118.0	59.0	1.8	3.8	3.4	7.30
	05/08/82	369	12.2	4.4	56.0	6.6	0.0	132.0	38.0	1.8	19.4	4.0	7.59
	03/09/82	365	14.3	4.4	62.0	7.0	0.0	160.0	39.0	0.0	14.6	1.7	7.75
	13/10/82	364	14.7	4.6	61.0	8.0	0.0	152.0	43.0	1.0	7.1	3.8	7.50
SG-9	16/07/80	330	17.0	4.8	65.0	7.0	4.0	209.0	16.0	6.0	1.3	5.4	7.65
	26/09/80	198	8.3	2.7	41.0	5.1	0.0	128.0	12.0	2.0		6.4	7.32
	23/04/81	231	8.8	2.4	54.0	5.8	0.0	121.0	33.5	4.0	1.0	7.2	7.66
	30/04/82	208	12.2	3.4	38.9	6.5	0.0	398.0	90.0	0.4	4.6	11.6	6.78
	28/05/82	527	53.0	12.0	80.0	9.2	0.0	133.0	232.0	0.6	0.9	10.5	7.38
	01/07/82	637	64.0	15.5	95.0	9.9	0.0	205.0	240.0	0.0	4.0	8.8	7.37
	05/08/82	473	31.1	8.6	82.0	9.4	0.0	244.0	84.0	0.0	4.0	4.4	7.66
	02/09/82	514	41.9	10.5	82.0	8.3	0.0	262.0	103.0	1.0	2.2	2.2	7.89
	13/10/82	540	40.3	10.4	100.0	7.6	0.0	250.0	119.0	0.0	5.0	9.0	7.73

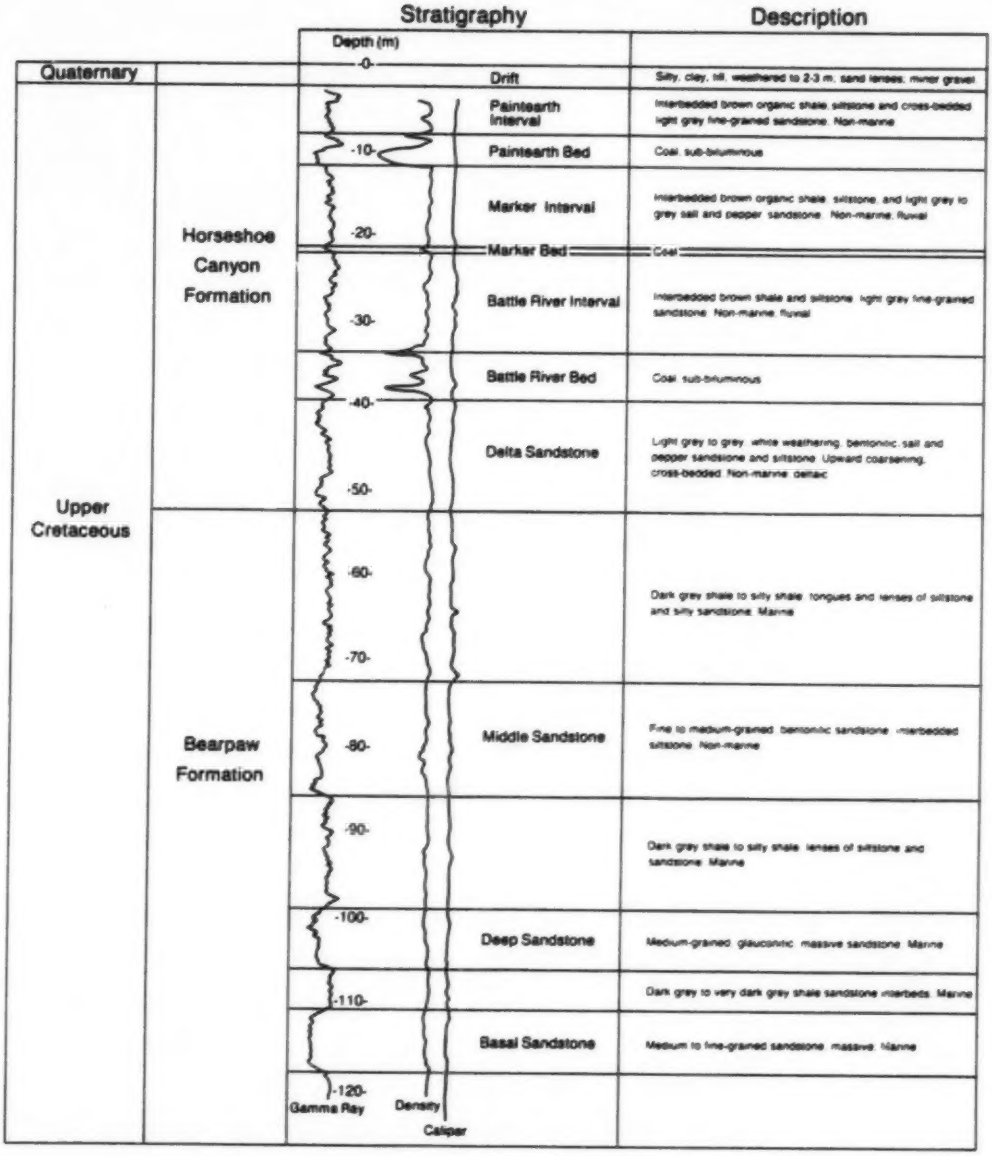
ND - no data.

3. CONTAMINATION OF SURFACE WATER BY SPOIL GROUNDWATER DISCHARGE AT THE BATTLE RIVER SITE

Groundwater is a significant component of stream flow within the study area only in the Battle River. Smaller streams in the area have an insignificant groundwater base-flow component, as evidenced by the extensive periods of zero discharge. The contribution of groundwater to flow in the Battle River has two components: (1) Base flow from sandstone aquifers within the Bearpaw Formation, situated from 0 to 30 m below river level, and possibly from deep-fill sediments within the Battle River valley; (2) Spring discharge from sandstone and coal outcrops of the Horseshoe Canyon Formation along the valley walls, with surface flow down to the river. The relative position of these coal and sandstone aquifers is shown in the stratigraphic column in Figure 6. Stratigraphically, the Battle River channel is situated between the middle sandstone and the deep sandstone of the Bearpaw Formation (Figure 6). Surface mining of coal removes the Battle River Bed of the Horseshoe Canyon Formation (Figure 6), and all material above the coal, replacing the natural sequence of coal and overburden with mine spoil. Along the Battle River valley the Battle River Bed outcrop and corresponding base of mine spoil occur approximately 50 m above river level. Further detail on the geology and hydrogeology of the area are presented in Maslowski Schutze et al. (1986) and Trudell et al. (1986).

Base flow from deep sandstone aquifers is not likely to be impacted by surface mining. These aquifers are separated from the zone of mining by as much as 60 m of predominantly fine-grained bedrock. On the other hand, the shallow groundwater flow system associated with springs along the valley walls, includes aquifers within and above the coal zone (Battle River Bed) or immediately below the coal zone (Delta Sandstone).

This shallow groundwater discharge occurs in both mined and unmined settings in the Battle River area as springs along the walls of the Battle River valley. Even though Paintearth Creek also flows



Stratigraphy			Description
Quaternary		Drift	Silty, clay, till, weathered to 2-3 m, sand lenses; minor gravel
Upper Cretaceous	Horseshoe Canyon Formation	Paintearth Interval	Interbedded brown organic shale, siltstone and cross-bedded light grey fine-grained sandstone. Non-marine
		Paintearth Bed	Coal, sub-bituminous
		Marker Interval	Interbedded brown organic shale, siltstone, and light grey to grey salt and pepper sandstone. Non-marine, fluvial
		Marker Bed	Coal
		Battle River Interval	Interbedded brown shale and siltstone, light grey fine-grained sandstone. Non-marine, fluvial
		Battle River Bed	Coal, sub-bituminous
		Delta Sandstone	Light grey to grey, white weathering, bentonitic, salt and pepper sandstone and siltstone. Upward coarsening, cross-bedded. Non-marine, deltaic
	Bearpaw Formation		Dark grey shale to silty shale, tongues and lenses of siltstone and silty sandstone. Marine
		Middle Sandstone	Fine to medium-grained, bentonitic sandstone, interbedded siltstone. Non-marine
			Dark grey shale to silty shale, lenses of siltstone and sandstone. Marine
		Deep Sandstone	Medium-grained, glauconitic, massive sandstone. Marine
			Dark grey to very dark grey shale sandstone interbeds. Marine
		Basal Sandstone	Medium to fine-grained sandstone, massive. Marine

Figure 6. Generalized stratigraphic column for the Battle River study Area.

in a deeply incised valley, there are no significant springs along the valley walls. In order to evaluate the potential contribution of spring discharge to surface water flows in the Battle River and the potential impact of mining on the quality of water in the river, a program of spring mapping was undertaken. This mapping program involved the location of springs, measurement of discharge rates, and sampling for chemical analysis.

Springs were mapped using colour air photographs in conjunction with foot traverses of the valley. Most of the mapping was carried out during very dry periods to minimize the potential for confusion with or masking by surface runoff or ponding due to precipitation. Springs were identified by the accumulation of salt crusts combined with growth of wetland-type vegetation along the valley walls. In almost all cases the source of water discharge in such settings could be traced to an outcrop face. Discharge measurements were made by funneling the flow from a given spring into a channel from which some volume of water could be collected over a period of time. It was possible to detect flows as low as 0.01 m^3/d by this method. Whenever possible at least three measurements were taken, and an average discharge calculated.

Along the 10 km reach of the Battle River that passes through the study area, 25 springs were identified. The locations of these springs are shown in Figure 7, and the discharge rates and chemical analyses are listed in Table 5. Fifteen springs occur along the north bank of the Battle River adjacent to the Diplomat Mine. On the basis of chemical composition of the groundwater illustrated on a piper trilinear diagram (Figure 8) and actual concentrations, ten of these springs are discharging water with characteristics similar to the spoil groundwater at the Diplomat Mine. These springs include SP80-4, 5; SP81-9, 10, 11, 12, 13, 14; and SP82-3 and SP82-4. In each case these springs are located in the Battle River valley below Diplomat Mine. The groundwater from these ten springs has a mean TDS concentration of 5819 mg/L (Standard Deviation = 2767 mg/L), and is characterized by the dominance of sulfate in the anion fraction (75%)

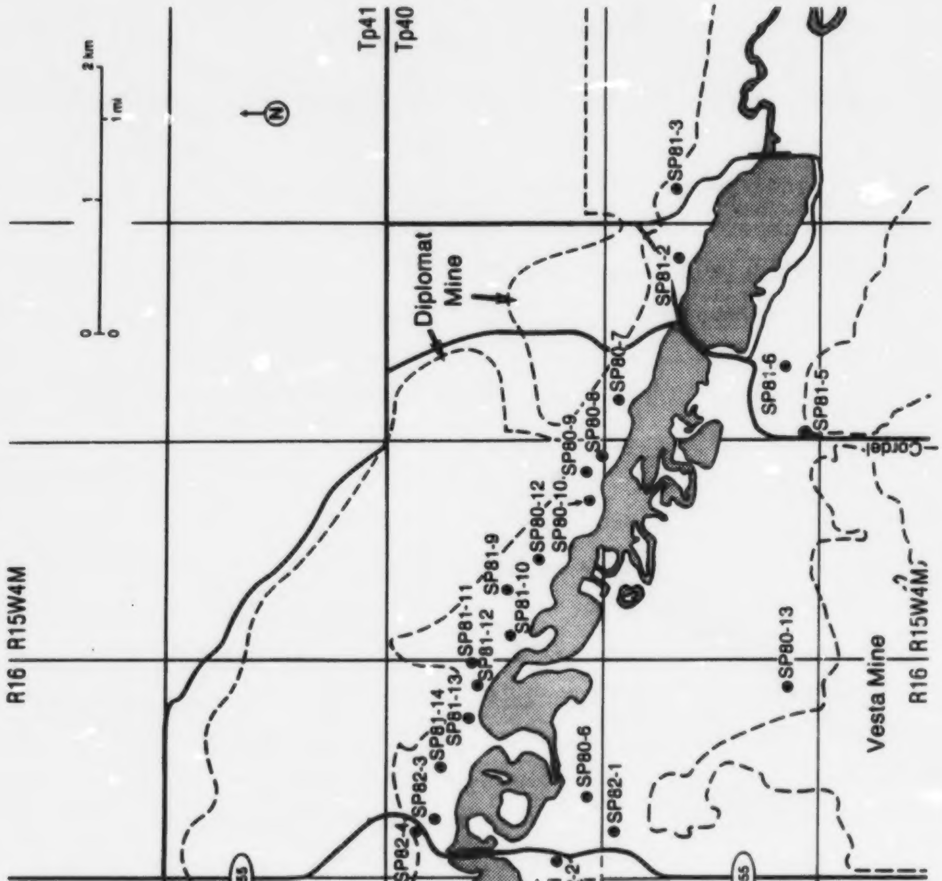

0
1
2 km
0
1 mi
N
Tp41
Tp40
R16 | R15W4M
Diplomat Mine
Battle
River
Big Knife Provincial Park
Bigknife
Creek
Paintearth
Creek
Control valve
See Figure 1
Cordel
Vesta Mine
855
SP81-1
SP81-2
SP81-3
SP81-5
SP81-6
SP81-7
SP81-8
SP81-9
SP81-10
SP81-11
SP81-12
SP81-13
SP81-14
SP80-4
SP80-5
SP80-6
SP80-7
SP80-8
SP80-9
SP80-10
SP80-12
SP80-13
SP82-1
SP82-2
SP82-3
SP82-4

Figure 7. Location of springs in the Battle River study area. SP81-1 is located at SW32-39-15-W4.

Table 5. Chemical analyses of water from springs.

Spring	Stratigraphic Unit or Lithology	Discharge m^3/day	TDS	Ca^{2+}	Mg^{2+}	Na^+	K^+	CO_3^{2-}	HCO_3^-	SO_4^{2-}	Cl^-	NO_3^-	pH
			mg/L										
SP80-4	Diplomat Spoil	5.18	3 302	214	56	707	7.8	0.0	519	1754	11	9.7	8.18
SP80-5	Battle River Bed	0.51	4 132	210	0.64	1004	9.5	0.0	553	2323	11	8.0	8.00
SP80-6	Battle River Bed/ Delta Sand	0.10	6 816	73	9.3	700	8.8	28.5	1397	4520	214	0.8	8.76
SP80-7	Unknown	12.64	2 476	208	76	412	7.0	0.0	533	1201	13	4.7	8.01
SP80-8	Middle Sandstone	0.04	5 235	13.1	12.8	1556	8.1	196	1640	1674	130	4.5	8.94
SP80-9	Middle Sandstone	0.02	5 052	10	8.9	1506	9.9	193	1471	1761	78	3.8	9.20
SP80-10	Middle Sandstone	1.49	2 273	9.5	2.9	719	1.1	0.76	1122	252	158	0.9	8.62
SP80-12	Delta Sandstone	12.76	3 380	114	35.9	831	6.2	0.0	625	1734	15	4.3	8.16
SP80-13	Battle River Bed	0.02	6 032	330	116	1212	15.0	0.0	535	3370	310	52	7.82
SP81-1	Sandstone	ND[a]	Not sampled										
SP81-2	Unknown	ND	Not sampled										
SP81-3	Delta Sandstone	2.58	1 586	142	41	250	8.2	0.0	547	567	4	5.7	8.30
SP81-5	Vesta Spoil	0.26	5 992	343	90	1362	15.4	0.0	212	3820	18	74	8.05
SP81-6	Vesta Spoil	9.29	2 760	182	29.5	532	15.4	0.0	511	1370	28	23.5	7.50
SP81-7	Battle River Bed	0.84	1 462	5.2	1.6	414	2.9	23.6	919	249	59.4	0.6	8.60
SP81-8	Battle River Bed	0.25	1 560	12.5	1.2	434	2.1	23.6	8.55	1.97	21	0.7	8.27
SP81-9	Delta Sandstone	0.06	12 081	204	174	3575	23.3	4.9	10.88	6949	46.6	0.5	7.80
SP81-10	Delta Sandstone	1.02	8 083	83	58	2338	11.7	78.6	1078	4400	24	1.2	8.41
SP81-11	Battle River Bed	17.20	5 052	63	11.8	1456	5.0	27.5	779	2690	10.6	0.5	8.64
SP81-12	Battle River Bed	7.13	6 859	128	50.6	1862	10.8	27.5	751	4000	16.2	0.7	8.57
SP81-13	Battle River Bed	1.43	6 106	469	191	1081	15.8	0.0	30.0	4265	24.6	2.1	5.01
SP81-14	Battle River Bed	5.79	6 480	155	16	2063	10.4	7.9	982	3210	21.0	0.3	8.40
SP82-1	Battle River Bed	14.15	1 033	19.9	11.5	248	2.8	7.7	448	279	1.0	1.0	8.60
SP82-2	Battle River Bed	5.53	1 339	25	21.3	291	3.1	2.6	774	192	9	6.1	8.24
SP82-3	Battle River Bed	23.04	4 299	86	18.9	1188	7.5	0.0	282	2669	14	16	7.69
SP82-4	Diplomat Spoil	32.14	3 471	400	129	440	11.4	0.0	654	1800	6	15	8.00

[a] ND: Not detectable.

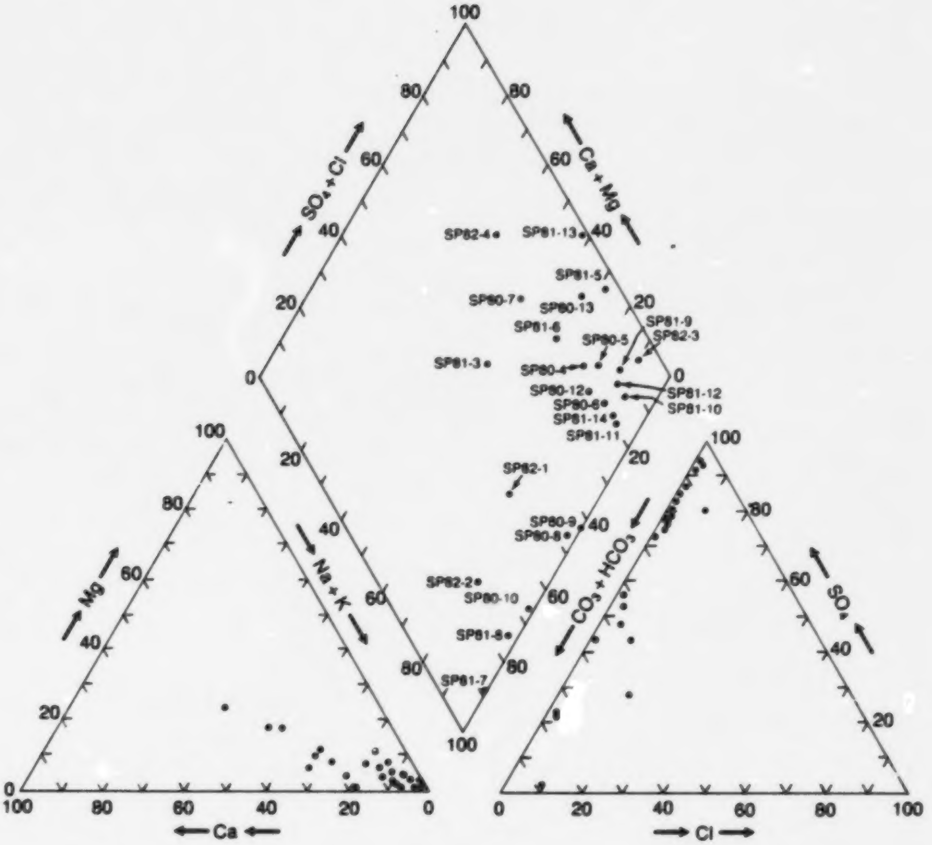


Figure 8. Piper trilinear diagram for spring water samples, Battle River site.

and sodium or sodium-calcium among the cation fraction (Na^+ 50% to 100%, Ca^{2+} 0 to 30%). This is quite similar to the spoil groundwater at Diplomat Mine, which is of Na^+, Ca^{2+} + Mg^{2+} - $SO_4{}^{2-}$, $HCO_3{}^-$ type with a mean TDS of 5875 mg/L (Standand Deviation = 1607). The springs identified as SP80-8, 9, and 10 discharge from the middle sandstone unit located below the coal zone, and represent a Na^+ - $HCO_3{}^-$, $SO_4{}^{2-}$ type of water that probably reflects a limited mixing of spoil groundwater with natural groundwater.

On the south bank of the Battle River four springs were identified adjacent to the Vesta Mine, SP80-6, 13 and SP81-5, 6. Springs SP80-6, 13 and SP81-5 in particular represent the discharge of spoil groundwater, with TDS ranging from 5992 mg/L to 6816 mg/L. The water from these springs is of Na^+, Ca^{2+} - $SO_4{}^{2-}$ type similar to that found in the spoil at Vesta Mine. The spoil groundwater at Vesta Mine is of Na^+, Ca^{2+} + Mg^{2+} - $SO_4{}^{2-}$, $HCO_3{}^-$ type with a mean TDS of 7035 mg/L (Standard Deviation = 2434). Spring SP81-6 discharges Na^+ - $SO_4{}^{2-}$ type water with 2760 mg/L TDS, and probably represents a mixing of spoil groundwater with fresh recharge water.

At least five springs represent natural groundwater discharge. SP81-7, 8 and SP82-1, 2 on the south bank of the Battle River have low TDS (1033 to 1560 mg/L) Na^+ - $HCO_3{}^-$, $SO_4{}^{2-}$ type water. In addition, spring SP81-3 on the north bank of the Battle River is located such that the influence of Diplomat Mine on water quality is minimal, and probably reflects natural groundwater quality. Water from this spring has less than 1600 mg/L TDS, with a Na^+, Ca^{2+} - $SO_4{}^{2-}$, $HCO_3{}^-$ composition. Spring 81-2, located near spring 81-3, was sealed off by a large slump failure of the valley wall in 1982, before it was sampled.

Despite the poor quality of spring water associated with mined lands, the total discharge of all springs is small relative to flows in the Battle River, and the overall impact on the river will be negligible. Long-term average daily flows for the Battle River measured by the Water Survey of Canada (station 05FC001) 8 km upstream from the study area, range from 5.32×10^4 m^3/d to

1.96×10^6 m^3/d during the ice-free period from April to November. The total daily salt load from spring discharge, calculated from discharge measurements and chemical analyses listed in Table 5 is 564 kg of salt per day. Assuming this loading to be constant during the period of April to November, the effect on water quality in the Battle River would be an increase in total dissolved solids from 0.3 to 10.6 mg/L during periods of high flows and low flows, respectively. Considering the Battle River mean TDS concentrations of 362 mg/L in spring (April to May) and 444 mg/L in autumn (September to October) for the last three years, the contribution of spring discharge to Battle River salinity represents 0.08% in spring, and 2.4% in autumn. No allowance has been made for seasonal variation in either discharge rate or quality of groundwater from the springs. In cases where shallow wells in the Battle River area have been sampled several times to evaluate seasonal variation in water quality, the variation was found to be relatively small. Variation in the discharge rate is unknown, but based on the magnitude of seasonal changes in water levels in shallow wells, it is not expected that the discharge rate will vary significantly over the year, at least in terms of the conclusions of this report. That is, the contribution of spring discharge to flow in the Battle River, as mapped, is extremely small, and changes in either the discharge rate of springs or the chemistry of the spring discharge, in response to climatic changes, is still expected to be negligible in terms of any effects on the Battle River.

4. CONCLUSIONS

The potential for contamination of surface water by spoil groundwater exists only along the reach of the Battle River that passes through the study area. Along the valley wall springs discharging water derived from mine spoil are contributing to the flow in the Battle River. However, the salt load derived from this spring discharge increases the salinity of the stream water by less than 1% during peak flows, and by less than 3% during autumn low flow periods. It is therefore concluded that the effect of spring discharge on the quality of water in the Battle River is, for practical purposes, negligible, and that even the elevated salinities associated with spoil groundwater discharge will not significantly alter the river water quality.

5. REFERENCES CITED

Maslowski Schutze, A., R. Li, M.M. Fenton, and S.R. Moran. 1986. Geology of the Battle River site: Plains Hydrology and Reclamation Project. Alberta Land Conservation and Reclamation Report #RRTAC 86-4.

Trudell, M.R., R.L. Faught, and S.R. Moran. In press. Hydrogeology and groundwater chemistry of the Battle River mining area. Alberta Land Conservation and Reclamation Report.